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REMOVAL OF TRIHALOMETHANE PRECURSORS BY DIRECT FILTRATION AND CONVENTIONAL TREATMENT

by

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16. ABSTRACT

This research examined direct filtration for the removal of trihalomethane (THM) precursors. Direct filtration pilot plant results were compared with the performance of two full scale conventional type water treatment plants. Two different water sources were studied - the Grasse River, a highly colored supply and the Glenmore Reservoir, a low turbidity, protected upland supply.

Direct filtration with cationic polymers as sole coagulants is an effective treatment process. Filtered water turbidities of 0.3 ntu or less and color less than 15 Pt-Co units were achieved. Average percent removals for non-purgable total organic carbon (NPTOC) and THM precursors were 37-39 and 41-42, respectively. This compares to average percent removals for the two conventional plants of 69-71 for NPTOC and 68-72 for THM precursors. Both conventional plants employed alum as the primary coagulant. This study showed that UV (254 nm) absorbance is a good surrogate parameter for predicting raw water NPTOC and THM precursors, for monitoring direct filtration performance for removals of these parameters, and for monitoring removals of these parameters by the two conventional water plants.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuirng its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This project was conducted to develop information on the removal of color and trihalomethane precursors by direct filtration, and on the monitoring of water plant operations when precursor removal is an operating goal. The results of this research can be used by water utilities attempting to meet the maximum contaminant level set for trihalomethanes in EPA's Drinking Water Regulations.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

Direct filtration facilities have been designed in the United States primarily on the basis of turbidity removal. With the issuance by EPA of a maximum contaminant level of 0.10 mg/L for trihalomethanes (THMs), there has been a need to investigate direct filtration for the removal of THM precursors, particularly for raw waters containing humic matter. This research project had two major objectives. First, direct filtration was investigated as a water treatment process using cationic polyelectrolytes as sole coagulants. Direct filtration was evaluated in terms of traditional filter performance - filtered water turbidity, color, and head loss - and in terms of removing non-purgable total organic carbon (NPTOC) and THM precursors. The second objective involved an investigation of THM formation through two full scale conventional type water treatment plants, and an evaluation of removals of NPTOC and THM precursors by these plants.

Direct filtration pilot plant studies were carried out on the Grasse River and the Glenmore Reservoir. The Grasse River is a low turbidity, highly colored supply, while Glenmore Reservoir is a protected, upland potable supply of low turbidity. The pilot plant results showed that cationic polymers are effective. In general, excellent performance was achieved with filtered water turbidity less than 0.3 ntu and apparent color less than 15 Pt-Co units. For both water supplies, there was little or no effect on filter performance between in-line direct filtration and direct filtration with flocculation, based on removals of turbidity, color, and organic matter. For the Grasse River, in particular, which contains high amounts of humic matter (sub-micron particles), there was substantially less head loss development when treating by direct filtration with flocculation compared to in-line direct filtration.

For the Grasse River, the following average percent removals were obtained by direct filtration with a cationic polymer: 58 for UV (254 nm) absorbance, 37 for NPTOC, and 42 for TTHMFP. Similar removals were obtained for Glenmore Reservoir as follows: 51 percent for UV (254 nm), 39 percent for NPTOC, and 41 percent for TTHMFP. The two full scale conventional water treatment plants (Grasse River at Canton, N.Y. and Glenmore Reservoir at Oneida, N.Y.), both use alum as a primary coagulant, and obtain greater removals of orgnic matter and THM precursors than direct filtration. The removals were similar for both plants with 80-82 percent for UV (254 nm), 69-71 percent for NPTOC, and 68-72 percent for Term TTHMs.

This study showed that UV (254 nm) is a good surrogate parameter for predicting raw water NPTOC and TTHMFP, for monitoring direct filtration

pilot plant performance for removals of NPTOC and TTHMFP, and for monitoring the removals of NPTOC and TTHMFP by the full scale conventional plants.

This report was submitted in fulfillment of Cooperative Agreement CR807034 by Clarkson College of Technology under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from January 3, 1980 to June 2, 1983, and work was completed as of June 4, 1983.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

α -- statistical significance of regression
$CHCl_3$ -- chloroform
$CHBrCl_2$ -- bromodichloromethane
$CHBr_2Cl$ -- dibromochloromethane
$CHBr_3$ -- bromoform
G -- mean square velocity gradient
gpm/ft^2 -- gallons per minute per square feet
Inst TTHM -- instantaneous total trihalomethane
MGD -- million gallons per day
ML/day -- million liters per day
mg/L -- milligrams per liter
m/hr -- meter per hour
NPTOC -- non-purgable total organic carbon
NVTOC -- non-volatile total organic carbon
ntu -- nephelometric turbidity unit
Pt-Co -- platinum cobalt units
r^2 -- coefficient of determination
r -- correlation coefficient
Term TTHM -- terminal total trihalomethane
THM -- trihalomethane
TOC -- total organic carbon
TTHMFP -- total trihalomethane formation potential
UV (254 nm) -- ultraviolet absorbance at 254 nm
μg/L -- microgram per liter

SYMBOLS (used in equations)

α -- collision efficiency factor
A -- area of flocculator paddles
C -- effluent suspended particle concentration
C_d -- drag coefficient
C_o -- influent suspended particle concentration
d_c -- diameter of collector
d_p -- diameter of suspended particles
f -- filter bed porosity
g -- gravitational constant
G -- mean square velocity gradient
h -- head loss
k -- Boltzmann's constant
L -- filter bed depth

LIST OF ABBREVIATIONS AND SYMBOLS cont'd.

η_D -- single collector efficiency due to Brownian diffusion
η_G -- single collector efficiency due to sedimentation
η_I -- single collector efficienty due to interception
ρ_p -- particle density
ρ_ℓ -- liquid density
μ -- fluid viscosity
t -- time
T -- absolute temperature
v -- relative velocity of flocculator paddles in fluid
v_o -- fluid velocity or filtration rate
V -- fluid volume in flocculation tank

APT-COL -- apparent color
Cl-2hr -- 2-hr chlorine demand
NPTOC -- non-purgable total organic carbon
SOL-UV -- soluble UV (254 nm) absorbance
TOTL-UV -- total UV (254 nm) absorbance
TTHMFP -- total trihalomethane formation potential

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This project could not have been completed without the cooperation of the Village of Canton, N.Y. and the City of Oneida, N.Y. In particular, I would like to acknowledge William Hamilton, Reggie Liscum, and Walter Rexford, water plant operators at Canton, for their interest and assistance. At Oneida, N.Y. the assistance of the chief operator, Nate Richter, is appreciated. I also thank Tony Glover, City of Oneida Water Superintendent. A special thanks goes to a special person, Rex A. Niles, who was Water Superintendent at Oneida until the summer of 1981.

William C. Becker was employed as a Research Sanitary Engineer on this project from January 1981 through June 1982. His dedication, hard work, and contributions to this study are greatly appreciated.

SECTION 1

INTRODUCTION

Direct filtration facilities for potable water treatment in the United States have been designed primarily on the basis of turbidity removal. Interest in direct filtration was stimulated following passage of the Safe Drinking Water Act by Congress in 1974 and the issuance of the National Interim Primary Drinking Water Regulations (NIPDWR). A turbidity standard of 1 ntu was set. Many communities which use low turbidity supplies and previously provided no treatment other than disinfection and pH control, are now faced with providing additional treatment to meet the turbidity limit of 1 ntu. While there is no primary standard for color, there is a secondary standard (no health concern) of 15 color units. Low turbidity, humic waters (colored waters) are normally treated by coagulation with aluminum salts (alum) in conventional treatment plants employing coagulation-flocculation, sedimentation, and filtration processes.

In addition to concerns about turbidity and color, it was found in the 1970's that trihalomethanes (THMs) are produced within water treatment plants as byproducts of chlorination (Rook, 1974; Bellar *et al.*, 1974; Symons, *et al.*, 1975). A variety of organic compounds (THM precursors) will react with chlorine to form trihalomethanes. The precursors may exist in dissolved, colloidal, or particulate forms in water supplies. Humic substances (natural color) constitute the major fraction of organic matter and THM precursors in most water supplies. In 1979 EPA amended the NIPDWR (Federal Register, 1979) by establishing a maximum contaminant level (MCL) of 0.10 mg/L for TTHMs. The effective dates for the regulations depend on community population: November 29, 1981 for systems serving 75,000 persons or more and November 29, 1983 for systems serving 10,000 to 75,000. Individual States may now exercise discretion and expand the coverage to systems serving less than 10,000, but it is expected that in the future the regulations will apply to nearly all water supplies.

There are several ways to reduce THM formation and remove THM precursors from water supplies. In 1982 EPA (Federal Register, 1982) identified what they considered the best generally available treatment methods. One of the methods is improved clarification either by conventional treatment or direct filtration. Direct filtration plants can offer savings in capital costs and operating costs when compared to conventional treatment. Since most direct filtration plants have been designed and operated for turbidity removal, there is a need to evaluate direct filtration for the treatment of low turbidity, humic waters. This research project examines direct filtration with respect to both problems addressed above, i.e., filter performance in terms of traditional parameters (turbidity and color) and removals of THM precursors and total organic carbon (TOC).

OBJECTIVES

This research project had two major objectives. First, direct filtration was investigated as a water treatment process using cationic polymers as the sole coagulant. In some experiments alum and polymer filter aids were also examined. Direct filtration was evaluated for the removal of turbidity and color, traditional parameters in assessing filter performance, and for removals of TOC and THM precursors. Second, two existing conventional water treatment plants were evaluated for THM formation through the plants and removals of THM precursors.

Direct filtration pilot plant studies were conducted on two different water supplies. One water supply, the Grasse River at Canton, N.Y., is a low turbidity, highly colored water. The other supply, the Glenmore Reservoir (Oneida, N.Y.) is a protected upland reservoir of low turbidity. To compare direct filtration results with conventional water treatment, the performance of the actual plants at Canton and Oneida was examined for THM precursor and TOC removals.

Specific objectives of the study were

- to characterize the raw water quality of both sources on a seasonal basis with respect to turbidity, color, non-purgable total organic carbon (NPTOC), total trihalomethane formation potential (TTHMFP), and UV (254 nm) absorbance;
- to examine the use of cationic polymers as sole coagulants in direct filtration (alum and polymer filter aids examined in a few experiments);
- to examine a variety of cationic polymers for direct filtration and determine the effect of raw water quality on polymer dosage requirements and performance;
- to examine the effects of various physical filtration variables (filtration rate, in-line direct filtration, direct filtration with flocculation and temperature) and chemical filtration variables (pH, various cationic polymers, and polymer dose) on filtration performance;
- to evaluate THM formation and removals of NPTOC and THM precursors for the two conventional water plants at Canton and Oneida;
- to compare direct filtration performance with the performance of the conventional water treatment plants;
- to investigate UV (254 nm) absorbance as a surrogate parameter for NPTOC and THM precursors.

SCOPE OF REPORT

This report is organized as follows. Conclusions and Recommendations are presented in Sections 2 and 3, respectively. Section 4 describes the procedures and analytical methods used in characterizing the raw waters and evaluating the two conventional water treatment plants. The pilot plants are described in detail in this section. Quality assurance procedures are incorporated into the discussion. Section 5 deals with characterization of the two raw waters. The two water supplies (Grasse River and Glenmore Reservoir) are described followed by presentation of the results of the characterization studies. Seasonal changes in turbidity, apparent color, NPTOC, THM precursors (TTHMFP), and UV (254 nm) absorbance are discussed. In Section 6 the Canton and Oneida water plants are described, followed by presentation and discussion of the results of the evaluation of the two water plants. This includes evaluation of THM formation through the water plants and evaluation of plant performance for removals of NPTOC, TTHMFP, and UV (254 nm) absorbance. Section 7 presents the results of small scale and large scale direct filtration experiments conducted at Canton on the Grasse River and at Oneida using Glenmore Reservoir water. Section 8 is a summary of the direct filtration studies with emphasis on practical applications of the research results. This section compares the removals of TOC and THM precursors by direct filtration with removals by the two conventional water plants. Cost estimates are also presented for direct filtration for 5 MGD (18.9 ML/d) plants at Canton and Oneida and compared with conventional type plants. Finally, in Section 9 surrogate parameters for NPTOC and THM precursors are examined. Emphasis is placed on UV (254 nm) absorbance as a surrogate. It is examined as a surrogate for predicting raw water NPTOC and TTHMFPs, as a process control parameter for monitoring direct filtration performance for removals of NPTOC and TTHMFP, and as a control parameter for the two conventional plants examined in this study.

SECTION 2

CONCLUSIONS

CHARACTERIZATION OF RAW WATERS

Both raw waters (Grasse River and Glenmore Reservoir) undergo a seasonal variation with highest concentrations of organic matter and THM precursors occurring in the late summer to early fall and lowest concentrations occurring during winter ice-cover periods. The Grasse River is a low turbidity, highly colored water supply with relatively high concentrations of humic substances. The range of values for NPTOC, TTHMFP (7-day, pH 7.5, 20°C), and UV (254 nm) absorbance during this study were 2.75-14.7 mg/L, 232-1108 μg/L, and 0.113-0.666 cm^{-1}, respectively. The Glenmore Reservoir is a protected upland water supply reservoir of low turbidity, and contains lower amounts of organic matter. The range of values for NPTOC, TTHMFP, and UV (254 nm) absorbance were 2.0-10.6 mg/L, 152-597 μg/L, and 0.084-0.309 cm^{-1}.

CONVENTIONAL WATER TREATMENT PLANT PERFORMANCE

The Canton Water Filtration Plant achieves excellent removals of TOC and THM precursors, and the finished water Inst TTHMs are low considering the high precursor concentrations in the Grasse River. During this study average removals for NPTOC, Term TTHMs (THM precursors), and UV (254 nm) absorbance were 69 percent, 72 percent, and 80 percent, respectively. The plant has tube settlers, thus the total hydraulic detention time through the plant excluding the clearwell is about 1 hr. The plant uses low prechlorination doses of 1-2 mg/L. This practice and the short hydraulic detention time allows removal of THM precursors before large amounts of precursors are converted into THMs. The Inst TTHM concentration of the finished water was 37 μg/L - average value for 16 monitorings over a two year period. This is extremely low considering the high precursor concentration of the raw water. In this plant, water temperature and pH also affect performance. Water temperature did not affect overall treatment plant efficiency for removals of organic matter and THM precursors; however, water temperature did affect sedimentation performance. For cold water conditions (data base of 5°C or less), the organic matter was coagulated, but settling was poor so that a large portion of the removal occurred by filtration in the winter.

The Oneida Water Treatment Plant also achieves excellent removals of TOC and THM precursors. After a plant start-up period, average removals for NPTOC, Term TTHMs, and UV (254 nm) absorbance were 71 percent, 68 percent, and 82 percent, respectively. As was the case with the Canton plant, water temperature did not influence overall treatment plant efficiencies, but did affect where the removals took place - lower percent removals by sedimentation under cold water conditions (data base of 10°C or less). The type and dosage of pre-disinfectant and/or oxidant had a significant effect on Inst TTHMs in the finished water. When prechlorination was practice, high concentrations of Inst TTHMs (2 cases, 134 and 148 μg/L) were found in the finished water. With the elimination of prechlorination by substituting $KMnO_4$ for Cl_2 as an oxidant for reduced iron and manganese, when needed, the average finsihed water Inst TTHM concentration was 27.5 μg/L (12 monitorings).

The percent removals of NPTOC, Term TTHMs (THM precursors), and UV (254 nm) absorbance were approximately the same for the Canton and Oneida water plants.

DIRECT FILTRATION

From the pilot plant studies conducted on the Grasse River at Canton the following conclusions are drawn.

- Jar tests can be used to select cationic polyelectrolyte dosages for direct filtration. The required polymer dose depends on the concentration of organic matter in the raw water, and can be predicted from apparent color or UV (254 nm) absorbance measurements.
- Cationic polyelectrolytes can be used as the sole coagulants in the treatment of low turbidity, humic waters by direct filtration. Raw water conditions of 50-200 Pt-Co units of color and turbidity of 1-6 ntu can be treated yielding filtered water of 5-10 Pt-Co units and 0.2 ntu.
- pH has a small effect on filtration performance for color and turbidity over the range of 5.5-7.5. Good filtration performance is achieved without pH adjustment.
- Using cationic polymers in direct filtration, the ranges of percent removals were 25-47 for NPTOC, 34-60 for TTHMFP, and 54-66 for UV (254 nm) absorbance. Higher removals occurred at lower pH conditions. Greater removals of organic matter can be obtained with alum.
- Filtration rate, in-line vs. direct filtration with flocculation, and water temperature had little or no effect on filter performance based on removals of organic matter, color, and turbidity.
- Head loss is greater for in-line filtration vs. direct filtration with flocculation for humic waters containing sub-micron particles. Providing a flocculation period can increase filter run time by reducing head loss.
- Most of the head loss occurs in the top of the filter bed. Most of the particles are removed there and act as filter media.

From the pilot plant studies conducted on the Glenmore Reservoir at Oneida the following conclusions are made.

- Jar tests can be used to select coagulant dosages for direct filtration.
- Cationic polymers can be used successfully in treating low turbidity, moderately colored waters. With raw water turbidities of 0.75-1.5 ntu and colors of 40-75 Pt-Co units, effluent turbidities of less than 0.3 ntu and colors of 5-15 Pt-Co units were obtained.
- The Glenmore Reservoir has a raw water pH of about 7.0. Good filtration results were achieve using a cationic polymer (Magnifloc 573C) at pH 5.0-5.9.
- Comparing effluent quality for in-line direct filtration vs. filtration preceded by flocculation, there was little effect on performance. There was a slight reduction in head loss development when flocculation was provided.
- The addition of a filter aid in conjunction with the cationic polymer increased removal of particles in the upper portion of the filter bed and prevented premature turbidity breakthrough.
- Direct filtration using cationic polymers is an effective means of removing organic matter which can act as THM precursors. Direct filtration at pH 5.5 to 6.0 produced average removals for TTHMFP, NPTOC, and UV of 41 percent, 39 percent, and 51 percent, respectively.
- Direct filtration experiments with alum achieved higher removals of organic matter.

For both the Grasse River and Glenmore Reservoir studies, removals of organic matter were similar for both small scale (4.45 cm ID filter columns) and large scale (0.372 m^2 filter bed area) pilot plants. This is an important conclusion since it means that results from small scale experiments can be extrapolated to large scale pilot plants or full scale plants.

Direct filtration with cationic polymers produced approximately equal percent removals of NPTOC and TTHMFP (THM precursors) for the Grasse River and Glenmore Reservoir. For the Grasse River, average removals for NPTOC and TTHMFP were 37 and 42 percent, while for the Glenmore Reservoir the NPTOC removal was 39 percent and the TTHMFP removal was 41 percent.

SURROGATE PARAMETERS

UV (254 nm) absrobance is a good surrogate parameter for predicting raw water NPTOC and TTHMFP (THM precursors) concentrations for both the Grasse River and Glenmore Reservoir. For the Grasse River r^2 values of 0.93 and 0.94 were obtained for NPTOC and TTHMFP, while for the Glenmore Reservoir the obtained values were 0.71 and 0.82.

UV can be used to monitor direct filtration pilot plant performance for removals of NPTOC and TTHMFP. For pilot plant studies on the Grasse River at Canton, r^2 values of 0.86 for NPTOC and 0.90 for TTHMFP were obtained for the respective predictive equations. For the Glenmore Reservoir (Oneida), r^2

values of 0.72 for NPTOC and 0.89 for TTHMFP were obtained.

Apparent color, total UV (unfiltered samples), and soluble UV (filtered samples) are all good surrogates for monitoring the removals of NPTOC and TTHMFP by the Canton and Oneida water treatment plants.

SECTION 3

RECOMMENDATIONS

Direct filtration studies on low turbidity and humic waters should be carried out using iron salts. These studies should examine removals of TOC and THM precursors. Cost comparisons should be made and compared to direct filtration using cationic organic polyelectrolytes and alum.

This research demonstrated the importance of providing a flocculation period in treating waters containing sub-micron particles (humic substances). Fundamental direct filtration studies should be conducted on a variety of waters in which particle size distributions of raw, filtered, and flocculated waters are made. Optimum conditions of filtration should be determined with respect to the size distributions of the particles being applied to the filter. The influence of flocculation period and the flocculation velcoity gradient on optimum conditions should be evaluated.

This research showed that UV (254 nm) absorbance is a good surrogate for predicing raw water TOC and THM precursors for the two water supplies examined. The utility of surrogate parameters such as UV should be examined on a variety of different type water supplies in the U.S.. This research also showed that UV could be used as a surrogate parameter to monitor direct filtration performance for removals of TOC and THM precursors. It also showed UV to be a good control parameter for the two full scale conventional water treatment plants studied. Additional field studies should be done under controlled conditions to determine the applicability of surrogate parameters such as UV for monitoring water plant performance.

SECTION 4

MATERIALS, PROCEDURES, METHODS, AND QUALITY ASSURANCE

Quality assurance is an essential and integral part of a research study. The term is sometimes mistakenly limited to the reliability of analytical methods. In a research project such as this, quality assurance procedures must also be applied to the laboratory experiments and field studies. The conditions and procedures used in the experiments and field studies must be subjected to quality assurance procedures. Quality assurance also addresses the procedures used in collecting, handling, and storing of water quality samples prior to analytical measurements.

In this section quality assurance procedures are not described separately. They are incorporated into and are an integral part of the descriptions of the materials used, the procedures followed, and the analytical methods employed to conduct the research.

MATERIALS

Low Organic Water

Low organic water was used to prepare chemical reagents and standards, and for dilution water. The water was prepared by passing distilled water through two mixed-bed ion exchange columns (IWT Research Demineralizers) in series, and then through two granular activated carbon columns (Filtrasorb 300, Calgon Company) in series. The flow rate through the second column was less than 0.5 bed volumes per hr. The water was stored in amber bottles at room temperature. The quality of the low organic water was checked against HPLC (high pressure liquid chromatography water, Baker Chemical Co.) water by measuring UV absorbance at 254 nm.

Chlorine Demand Free Water

This water was used to prepare chlorine solutions and reagents associated with chlorine measurements. Nine liters of distilled water were chlorinated with 10 mL of 5% sodium hypochlorite. The water was then stored in a glass container for several days with exposure to direct sunlight to aid chlorine dissipation. The water was not used until no free residual chlorine was detected.

Alum

Reagent grade aluminum sulfate ($Al_2(SO_4)_3 \cdot 16\ H_2O$) was used for the small scale direct filtration plant studies. The Canton and Oneida water treatment plants both use liquid alum (~48.5% $Al_2(SO_4)_3 \cdot 14\ H_2O$) from the Holland Company, Inc. (Adams, Mass.). Liquid alum was obtained from each water plant and used in the large scale (Waberboy) filter experiments.

Polymers

Fourteen cationic polyelectrolytes were obtained from Nalco Chem. Co., Betz Laboratories, Calgon Corp., and American Cyanamid (Magnifloc) and used in jar test studies. These polymers are listed in Table 1. All of the polymers are approved for use in potable water treatment (U.S. EPA, 1979).

For the jar tests, stock solutions of 10 g/L were prepared quarterly in low organic water and stored in the dark at room temperature. On a monthly basis, 1 g/L stock solutions were prepared. From this, working dilutions were prepared on a daily basis.

A smaller number of polymers were used in pilot plant studies (see Table 1). For these studies, fresh solutions were prepared at appropriate concentrations as needed.

Three high molecular weight (MW ~10^7) polymers were tested as filter aids in pilot plant studies at Oneida: Calgon L650E, Magnifloc 985N, and Betz 1160. The L650E, and 985N are very slightly anionic in charge (generally considered as nonionic), and the Betz 1160 polymer has a very small cationic charge. These polymers are also approved for potable water treatment with maximum concentrations of 4, 1, and 1 mg/L for L650E, 985N, and 1160, respectively (U.S. EPA, 1979).

PROCEDURES

For the purpose of describing experimental procedures the work is described according to five study phases.

- Raw Water Characterization (RWC)
- Conventional Water Treatment Plant Evaluation (CWTP)
- Jar Tests (JT)
- Small Scale Pilot Plant (SSPP)
- Large Scale Pilot Plant (LSPP)

The water quality parameters measured in each phase are listed in Table 2. Here the procedures are described including sample collection and handling. The pilot plants are also described here in detail including quality assurance procedures used to calibrate chemical feeds and flows. Analytical methods are described later in Section 4.

Procedures used in cleaning glassware, particularly glassware used in TOC and THM analyses, are described in Appendix A.

TABLE 1. LIST OF CATIONIC POLYMERS USED IN RESEARCH

Polymer	Characteristics	Max. Conc.* (mg/L)	Jar Test	Pilot Plant+	
				SS	LS
Nalco 8101		20	x		
Cat Floc T	quaternary, dimethyldiallylamine chloride	50	x	x	
Cat Floc T1	similar to Cat Floc T, lower MW	50	x		
Cat Floc 21		50	x		
Cat Floc 121		60	x		
Betz 1190	polyquaternary amine	25	x	x	x
Betz DK-724		50	x		
Magnifloc 515C	melamine formaldehyde	50	x		
Magnifloc 521C		10	x		
Magnifloc 572C	polyquaternary amine	20	x	x	x
Magnifloc 573C	polyquaternary amine	20	x	x	x
Magnifloc 581C	polyquaternary amine	20	x	x	
Magnifloc 585C	polyquaternary amine	50	x	x	
Magnifloc 587C		50	x		

* Maximum concentration allowed for potable water treatment (U.S. EPA, 1979)

+ Used in small scale (SS) pilot plant studies or large scale (LS) Waterboy studies.

TABLE 2. MEASURED WATER QUALITY PARAMETERS

Parameter	Study Phase*					Method
	RWC	JT	CWTP	SSPP	LSPP	
Temp	x	x	x	x	x	Hg Thermometer (1)
pH	x	x	x	x	x	Electrometric - pH Meter (1)
Turbidity	x	x	x	x	x	Nephelometric (1)
App. Color	x	x	x	x	x	Spectrophotometric (2)
True Color	x	x	x			Spectrophotometric (2)
Total UV	x	x	x	x	x	Spectrophotometric (2)
Soluble UV	x		x			Spectrophotometric (2)
NPTOC	x		x	x	x	Combustion-Infrared (1)
Inst TTHM			x			Liquid/Liquid Extraction - GC (1,3)
Term TTHM			x			Liquid/Liquid Extraction - GC (1,3)
TTHMFP	x		x	x	x	Liquid/Liquid Extraction - GC (1,3)
Free Cl_2			x			DPD Colorimetric & Amperometric (1)

* RWC (Raw Water Characterization); JT (Jar Tests); CWTP (Conventional Water Treatment Plant Evaluation); SSPP (Small Scale Pilot Plant); LSPP (Large Scale Pilot Plant).

(1) Standard Methods (APHA, 1976 and 1980)

(2) See text

(3) Federal Register, 1979

Raw Water Characterization

Raw water samples were collected from both supplies (Grasse River, Canton, N.Y. and Glenmore Reservoir, Oneida, N.Y.) on a seasonal basis to characterize the water supplies with respect to concentrations of organic matter and to identify seasonal trends. The frequency of sampling was bimonthly or greater for the Grasse River for the period February 28, 1980 to March 24, 1982. Raw water measurements associated with the evaluation of the conventional water treatment plant at Canton and the direct filtration pilot plant studies were added to the data base yielding measurements for 57 dates for the 25 month period. The Glenmore Reservoir was sampled in a similar fashion resulting in 44 sampling dates between February 25, 1980 and June 22, 1982.

The water quality parameters measured are listed in Table 2. Sampling procedures follow for TOC and TTHMFP measurements.

TOC Sampling--

Samples for TOC were collected in 25 or 40 mL screw cap, glass vials with TFE septa. Two drops of 1:1 HCl were added to the vials prior to sampling to preserve the sample at a pH of about 2. For Grasse River work, the samples were returned to the environmental engineering laboratory at Clarkson within 2 hrs. Samples were then stored in a refrigerator at 4°C.

Similar procedures were used for Glenmore Reservoir sampling with the following exception. The Glenmore Reservoir is approximately 135 miles (driving distance) from Potsdam. When returning to Clarkson on the same day of collection, the samples were placed in a cooler and returned immediately to the laboratory at Clarkson within 4 hrs. Other samples were stored at the Oneida Water Treatment Plant at 4°C for up to three days prior to being returned to Clarkson. At Clarkson, all samples were stored at 4°C.

TTHMFP Sampling--

Samples used to produce THM formation curves were collected headspace free in 2 liter glass bottles and returned to the laboratory. When only 7-day TTHMFPs were measured, samples were collected headspace free in 125 mL amber bottles with TFE faced septa (Pierce Chemical Co.). The in-transit times (collection to arrival at the laboratory) for Grasse River and Glenmore Reservoir samples are identical to those described for TOC sampling.

Upon arrival in the laboratory, samples were immediately chlorinated with a sufficient dosage of chlorine to maintain a free chlorine residual for 7-days. Selection of Cl_2 doses was not done on a rigorous basis, but did fall within the following Cl_2 to TOC ratios: 4-5 mg/L Cl_2 per mg/L TOC for Grasse River samples and 3-5 for Glenmore Reservoir samples. The Cl_2 to TOC ratio will affect the kinetics of THM formation, but should only have a minor effect on the extent of the THM reaction. The 7-day TTHMFP is used in this research as an indirect measure of THM precursors. If we assume that it is, approximately, a measure of the extent of the THM formation reaction, the 7-day TTHMFP should be independent of chlorine dose as long as a free chlorine residual exists after 7 days. This is demonstrated by the results in Table 3. There are no real differences among the numbers if one accounts for the THM associated with the chlorine stock solution - assumed source of THM ($CHCl_3$) in blank.

TABLE 3. 7-DAY TOTAL TRIHALOMETHANE FORMATION POTENTIALS (pH 7.5, 20°C) FOR THREE APPLIED CHLORINE DOSES (GRASSE RIVER SAMPLE COLLECTED 1/26/81)

	Applied Cl_2 (mg/L)	Cl_2/TOC (mg/mg)	Free Cl_2* (mg/L)	TTHMFP (μg/L)
Blank+	10	-	9.6	8.4
Sample	12	3.7	3.4	240
Sample	15	4.7	5.9	255
Sample	30	9.3	>19	268

* Measured at end of 7-days.

+ Blank of low organic water chlorinated at pH 7.5, 20°C, and held for 7-days.

Chlorine stock solutions of 1000 mg/L were prepared in chlorine demand free water from a 5% sodium hypochlorite solution. Standardization of the stock was performed by idometric titration according to Standard Methods (APHA, 1980).

Figure 1 shows a schematic diagram summarizing handling of TTHMFP samples. Note that all TTHMFPs were done under constant pH and temperature conditions - pH 7.5 at 20°C. To maintain a pH of 7.5, 1 mL of a phosphate buffer (0.044 M KH_2PO_4/0.152 M Na_2HPO_4) was added to the 125 mL bottle prior to chlorination. Samples were transferred to 25 mL (or 40 mL) vials containing ~0.2 mg sodium sulfite (solid) to quench the THM reaction. pH and free residual chlroine were checked on the remaining sample. The pH was always within ± 0.1 of 7.5, and for all the data reported the free chlorine concentration was always greater than 0.5 mg/L. The quenched samples were stored at 4°C headspace free until gas chromatographic analysis was performed.

Background THM levels for the two water supplies were analyzed each time raw water samples were collected. These are labeled blanks (unchlorinated) in Figure 1. In all cases the results showed no THMs above the detection limit - less than 1 μg/L for TTHMs.

Other Parameters--

For Glenmore Reservoir sampling, all parameters other than TOC and TTHMs were measured in the field at the Oneida Water Treatment Plant at the time of collection.

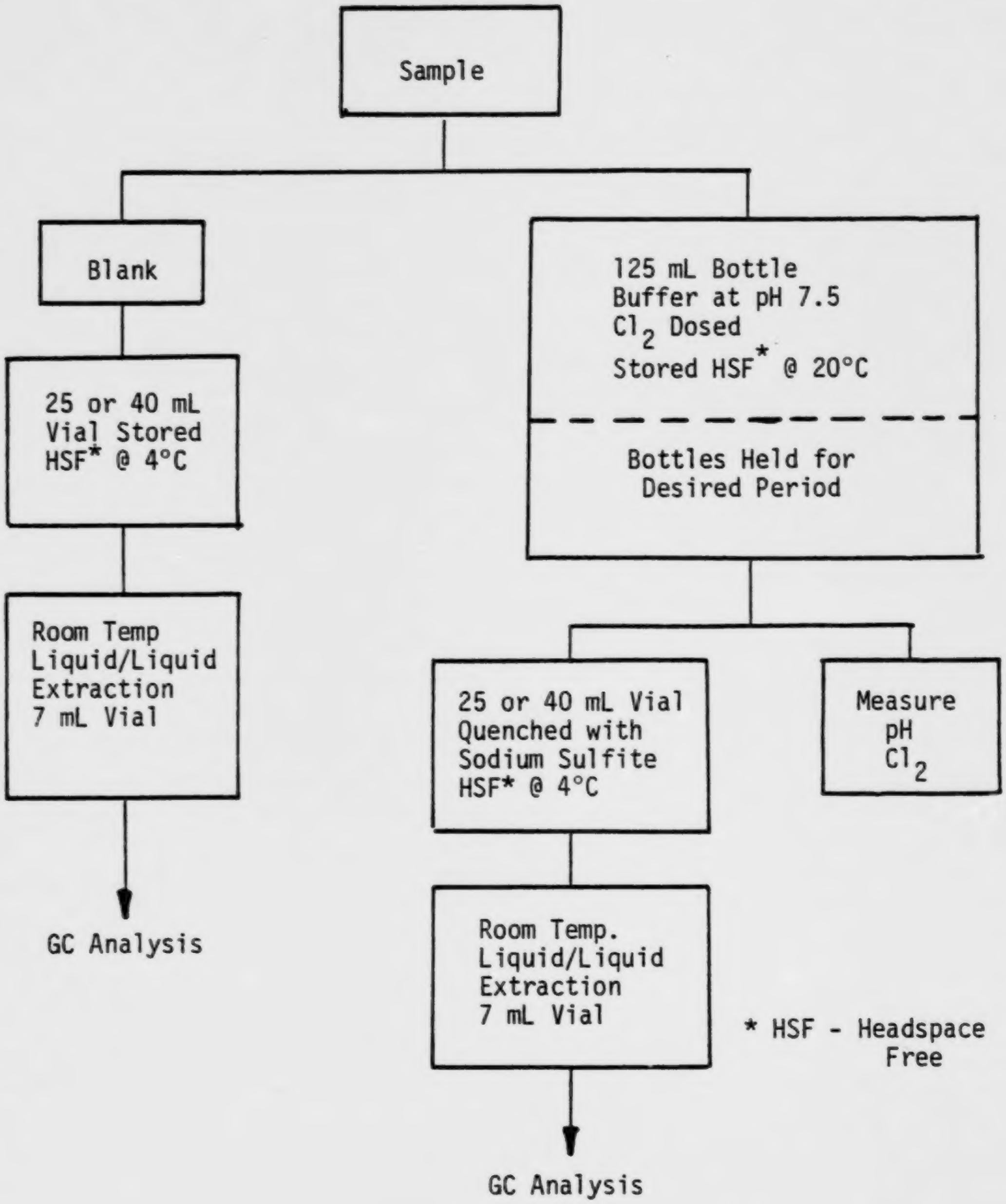

Sample
Blank
25 or 40 mL Vial Stored HSF* @ 4°C
Room Temp Liquid/Liquid Extraction 7 mL Vial
GC Analysis
125 mL Bottle Buffer at pH 7.5 Cl_2 Dosed Stored HSF* @ 20°C
Bottles Held for Desired Period
25 or 40 mL Vial Quenched with Sodium Sulfite HSF* @ 4°C
Measure pH Cl_2
Room Temp. Liquid/Liquid Extraction 7 mL Vial
* HSF - Headspace Free
GC Analysis

Figure 1. Schematic diagram for sample handling for total trihalomethane formation potentials.

For the Grasse River, pH and temperature were measured in the field. Samples for the other parameters (see Table 2) were returned to the laboratory at Clarkson and measured immediately, usually within 2 hrs.

Conventional Water Treatment Plant Performance

A monitoring program of the Canton and Oneida water plants was conducted. The purpose was to evaluate TOC and THM precursor removals by these conventional water treatment plants and to compare the results with direct filtration performance (pilot plant studies). The water plants and sampling points are described in Section 6.

Table 2 lists those water quality parameters measured in this phase of the study. For monitoring of the Oneida plant, all measurements were made on-site except TOC and THMs. For Canton, temperature, pH, turbidity, and free residual chlorine were measured on-site at the water plant. Other parameters were measured on samples returned to the Clarkson laboratory. Usually these measurements were made within 2 hours.

Sampling procedures for TOC and TTHMFP followed those previously described. Procedures for Inst TTHMs and Term TTHMs follow with some additional comments regarding TTHMFPs.

Instantaneous Trihalomethanes--

The conventional water treatment systems at Canton and Oneida were monitored for THM formation. Samples for instantaneous total trihalomethane (Inst TTHM) determinations were collected in 25 mL screw cap vials (TFE faced septa). The vials contained sufficient sodium sulfite to reduce any free chlorine and halt THM formation. The vials were filled headspace free, and immediately returned to the laboratory where they were stored at 4°C.

Terminal Trihalomethanes--

In the water treatment plant monitoring studies, samples for Terminal Trihalomethanes (Term TTHMs) were collected and set up in the field. Samples were collected in 125 mL amber bottles containing the phosphate buffer (1 mL of 0.044 M KH_2PO_4/0.152 M Na_2HPO_4) to give a pH of 7.5. The bottles were filled to overflowing, and then the samples were chlorinated with sufficient chlorine to maintain a residual for 7-days. The samples were immediately returned to the laboratory where they were stored for 7-days at 20°C. At the end of 7-days, an aliquot was transferred to 40 mL vials containing sodium sulfite. These vials were stored headspace free (TFE faced septa) at 4°C.

Total Trihalomethane Formation Potential--

The TTHMFP is the difference between the Term TTHM and the Inst TTHM. For the raw waters (unchlorinated) entering the treatment plants at both Canton and Oneida, no Inst TTHMs were detected so raw water 7-day TTHMFPs are equal to the 7-day Term TTHMs.

For raw waters, 7-day TTHMFPs are used as an indirect measure of the THM precursor concentration. For the direct filtration pilot plant studies in which no Cl_2 was used in the pilot plant, THM precursor removal is evaluated by comparing raw water TTHMFPs with filter effluent TTHMFPs. For the actual water treatment plants where Cl_2 is used and THMs are formed through the plant (Inst TTHMs), precursor removal is based on comparing 7-day Term TTHM of the raw (equal to the 7-day TTHMFP) to the finished water Term TTHM.

Jar Tests

Jar tests were used to screen polymers for their ability to destabilize color and to estimate polymer (coagulant) dosages for direct filtration. The bulk of the experiments involved polymer evaluation; in several experiments, alum was the coagulant. Jar test procedures were similar. A six-place jar test machine (Phipps and Bird, Inc.) was used and generally the procedures were as follows:

(1) Samples (500 or 1000 mL) were pH adjusted, if desired, with HCl or NaOH.

(2) Samples were dosed with varying amounts of coagulant and rapid mixed for 2 minutes at 100 rpm.

(3) Samples were slow mixed at 20 rpm for 20 minutes.

(4) At the end of the slow mix period, the jar test machine was shut off and paddles removed from the samples. A settling period of 30 minutes was used.

(5) Supernatant samples (collected from just below the water surface) were analyzed for turbidity and apparent color (in some experiments total UV (254 nm) absorbance was also measured). An additional sample was also withdrawn from the beakers for true color.

On occasions when jar tests were conducted at a water temperature below 15°C, the flocculation and settling periods were extended. This was done because at lower temperatures fluid viscosity is high which decreases floc settling. In order to interpret the jar test data with respect to the ability of cationic polymers to destabilize the humic substances (color), and not be concerned about floc settling characteristics, the flocculation period was extended to 1 hr and the settling period to 45 min.

Small Scale Pilot Plants

The purpose of this section is to describe in some detail the design, configuration, and operation of the small scale direct filtration pilot plants. The pilot plants were designed to be small and flexible. Two identical pilot plants were constructed. One was set up on site at the Canton Water Filtration Plant, the other at the Oneida Water Treatment Plant. Figure 2 is a detailed schematic of one side of a small scale pilot plant. There were two identical sides permitting operation of two filters under different conditions.

Flexibility was built into the system. Coagulant or a combination of two coagulants could be added continuously. As shown in Figure 2, flocculation (through a flocculator) could be employed or by-passed (in-line direct

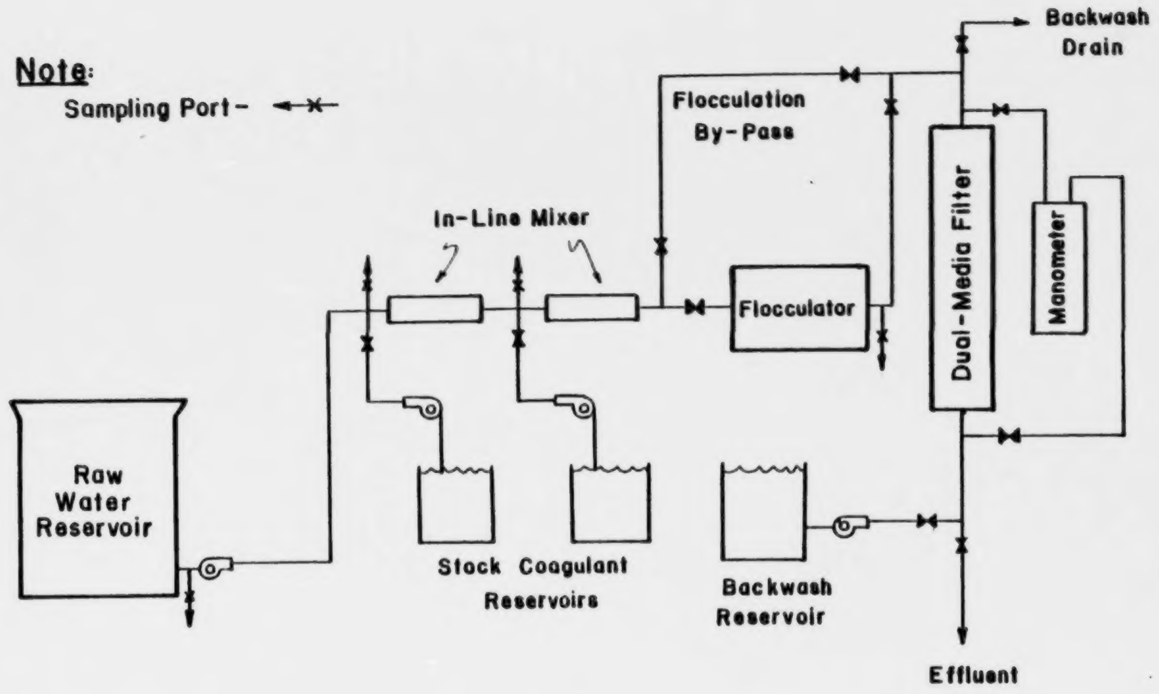

Note:
Sampling Port - ←×—
Raw Water Reservoir
In-Line Mixer
Stock Coagulant Reservoirs
Flocculation By-Pass
Flocculator
Backwash Reservoir
Dual-Media Filter
Manometer
Backwash Drain
Effluent

Figure 2. Schematic of small scale direct filtration pilot plant.

filtration). Procedures are described next. Pertinent data regarding operating conditions and filter media characteristics are summarized in Table 4.

Raw Water Pumping System--

The raw water was pumped from a 200 liter polypropylene storage tank with a positive displacement pump (Fluid Metering Inc., Model RPD-2). During filter experiments which required pH adjustment, 1.0 N HCl was added to the raw water reservoir. The water was completely mixed for several minutes with air using two stone diffusers located at the bottom of the tank. Air was supplied at 10 psi through a cleaning system consisting of 0.1 N H_2SO_4, distilled water and a glass wool filter in series. Flow rates were checked initially and periodically during a filter run by volumetric measurements - i.e., determining the volume of water delivered to a graduated cylinder for a known time.

Coagulant Feed System--

Coagulant (typically, liquid cationic polyelectrolytes) was continuously introduced into the raw water system through a 0.64 cm OD polypropylene cross-tee located just ahead of the in-line static mixer. A concentrated feed solution (1000-2000 mg/L) of polymer was pumped from a 1 liter graduated cylinder with the use of a perstaltic laboratory pump (Scientific Industries, Model 203).

Polymer feed rates were determined by two methods. Prior to initial start-up of a filter run, the polymer feed rate was measured directly at the cross-tee. During the run, the feed rate was determined by measuring the polymer level in the graduatedcylinder for a selected time interval. The polymer was added just ahead of a 0.64 cm OD static mixer (Kenics Corp., Model KBUL-2) for complete mixing of the polymer into the water being treated.

In some experiments alum was used alone or combinations of coagulants were examined. Similar quality assurance procedures as described above were followed to ensure proper determination of coagulant dosages.

Flocculation Chamber--

A detailed drawing of the flocculator is presented in Figure 3. The flocculation chamber was constructed of plexiglass except where noted. The flocculator maintained a fluid volume of 3038 ml and yielded a flocculation period of 12 minutes for filter runs which utilized a filtration rate of 9.76 m/hr (4 gpm/sq ft). Two identical flocculators were constructed. Operation of these in series at a filtration rate of 9.76 m/hr yielded a total flocculation period of 24 minutes.

Four baffles were incorporated in the design to ensure good mixing. A pressure relief outlet located on the upper flange of the flocculator was provided to allow air to evacuate from the chamber during filling. Tygon tubing (0.16 cm ID) was inserted into the pressure relief outlet and a pinch clamp was used to close the system when the chamber was entirely filled. A stainless steel paddle was sealed in the flocculator to provide the required

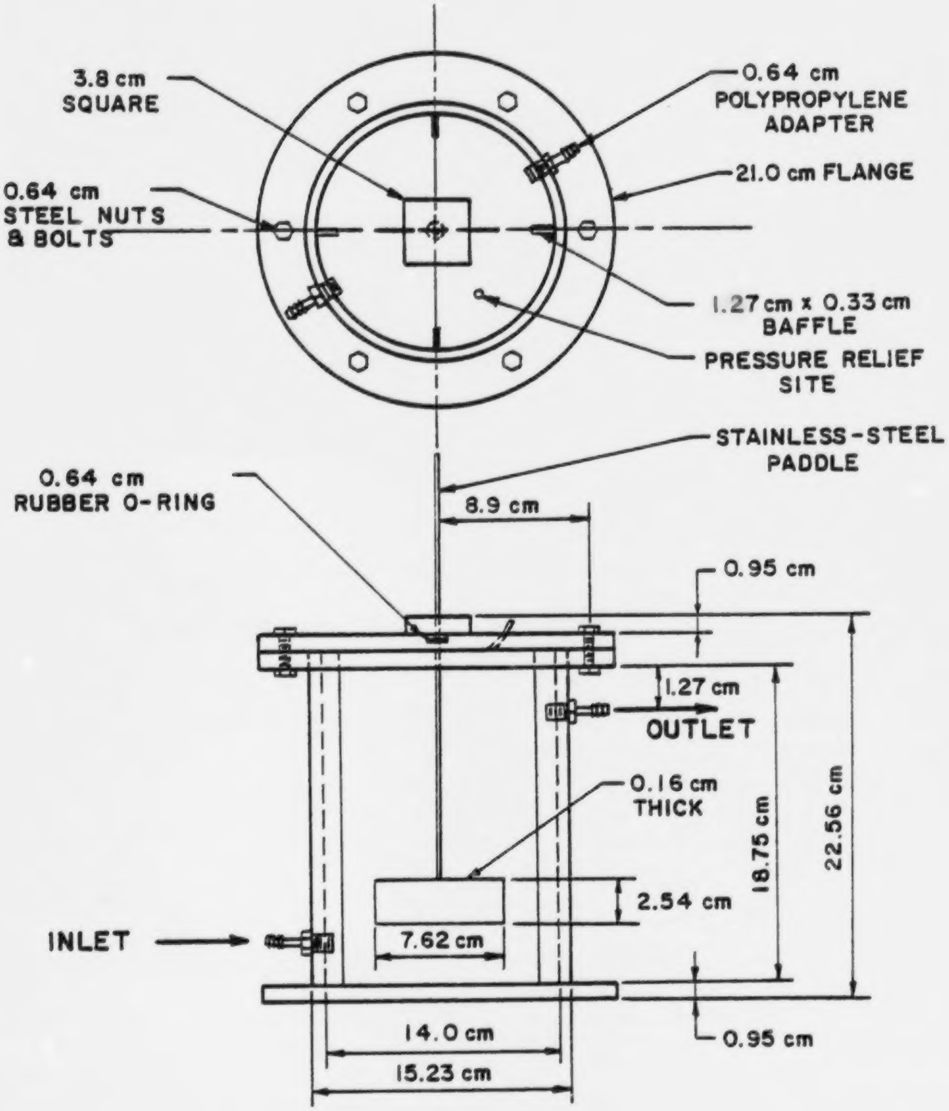
TABLE 4. SMALL SCALE DIRECT FILTRATION SYSTEM

Flow Rate	63.3 or 126.5 mL/min
Flocculation	0, 24, or 48 minutes
Filtration Rate	4.88 or 9.76 m/hr
Filter Area	15.5 cm^2
Filter Media Depth	38.1 cm anthracite 15.2 cm sand
Filter Media Effective Size	1.0-1.2 mm anthracite 0.45-0.55 mm sand
Filter Media Uniformity Coefficient	1.33 anthracite 1.49 sand

TABLE 5. PILOT PLANT ORGANICS LEACHING EXPERIMENT

Sampling Pt.	TTHMFP* (μg/L)
Distilled Water	136
Reservoir Effluent	93
Filter Effluent	88

* 8-hr TTHMFP (pH 7.5, 20°C), Cl_2 Dose 7.9 mg/L.



3.8 cm SQUARE
0.64 cm POLYPROPYLENE ADAPTER
21.0 cm FLANGE
0.64 cm STEEL NUTS & BOLTS
1.27 cm x 0.33 cm BAFFLE
PRESSURE RELIEF SITE
STAINLESS-STEEL PADDLE
0.64 cm RUBBER O-RING
8.9 cm
0.95 cm
1.27 cm
OUTLET
0.16 cm THICK
18.75 cm
22.56 cm
2.54 cm
INLET
7.62 cm
14.0 cm
15.23 cm
0.95 cm

Figure 3. Detailed drawing of small scale flocculator.

slow mixing. A Phipps and Bird jar test machine was used as the power source.

Pilot Filters--

The filter columns were made of plexiglass with a 4.45 cm ID and a total depth of 93.1 cm as shown in the detailed drawing in Figure 4. At the base of the column, a porcelain Buchner funnel (4.45 cm ID) was used to support the filter media. The pores of the funnel were utilized to provide a uniform distribution of water through the column during backwashing. The funnel was supported by two flanges with the aid of four 0.64 cm OD steel bolts. A #40 nylon sieve cloth was used to prevent sand from escaping through the funnel. A 0.18 cm thick neoprene gasket was inserted on the top flange of the filter to prevent water leaks and air intrusion. Two manometers were used to monitor head loss development through the filter. Tygon tubing connected the manometer ports to a wall-mounted mercury manometer (Dwyer Series, Inc., Series 1223 U-tube manometer).

Filter materials were purchased from Unifilt Corp.. The filter bed consisted of 38.1 cm of anthracite on top of 15.2 cm of sand. Filter media characteristics are detailed in Table 4. The filter bed porosity was 0.4 for all filter experiments.

A concern in performing small scale laboratory filter experiments is the avoidance of wall effects arising from the use of small diameter columns and relatively large media. Rose (1951) conducted a study of wall effects and head loss for packed beds, and related relative column resistance (wall effects) to the Reynolds Number and to the ratio of column diameter to media diameter. For this work, a relative column resistance of 1.06 was calculated indicating negligible wall effects. This calculation was based on a Reynolds Number of 10 (a conservative value for the filtration conditions employed in this research) and for a column diameter to filter media ratio of 34 (44 mm/ 1.2 mm).

Another concern was the possibility of organic leaching from the pilot filter system (tubing, connectors, storage tanks, and filter columns). Such an occurrence would lead to erroneous results in all organic and trihalomethane measurements. An experiment was conducted using distilled water. Distilled water was pumped from the raw water reservoir through the pilot filter plant. Samples were collected and 8-hr TTHMFPs (pH 7.5, 20°C) measured. The results are summarized in Table 5. Although the distilled water contains THM precursors, there was a loss of precursors through the pilot plant indicating that the pilot plant does not act as a source of THM precursors.

Typical Experiment--

General procedures followed in performing an experiment are outlined in the following steps.

(1) Raw water was collected as previously described. Temperature, pH, apparent color, and total UV (254 nm) absorbance were measured in the field. Samples for TOC and TTHMFPs were collected and returned to Clarkson's environmental laboratory.

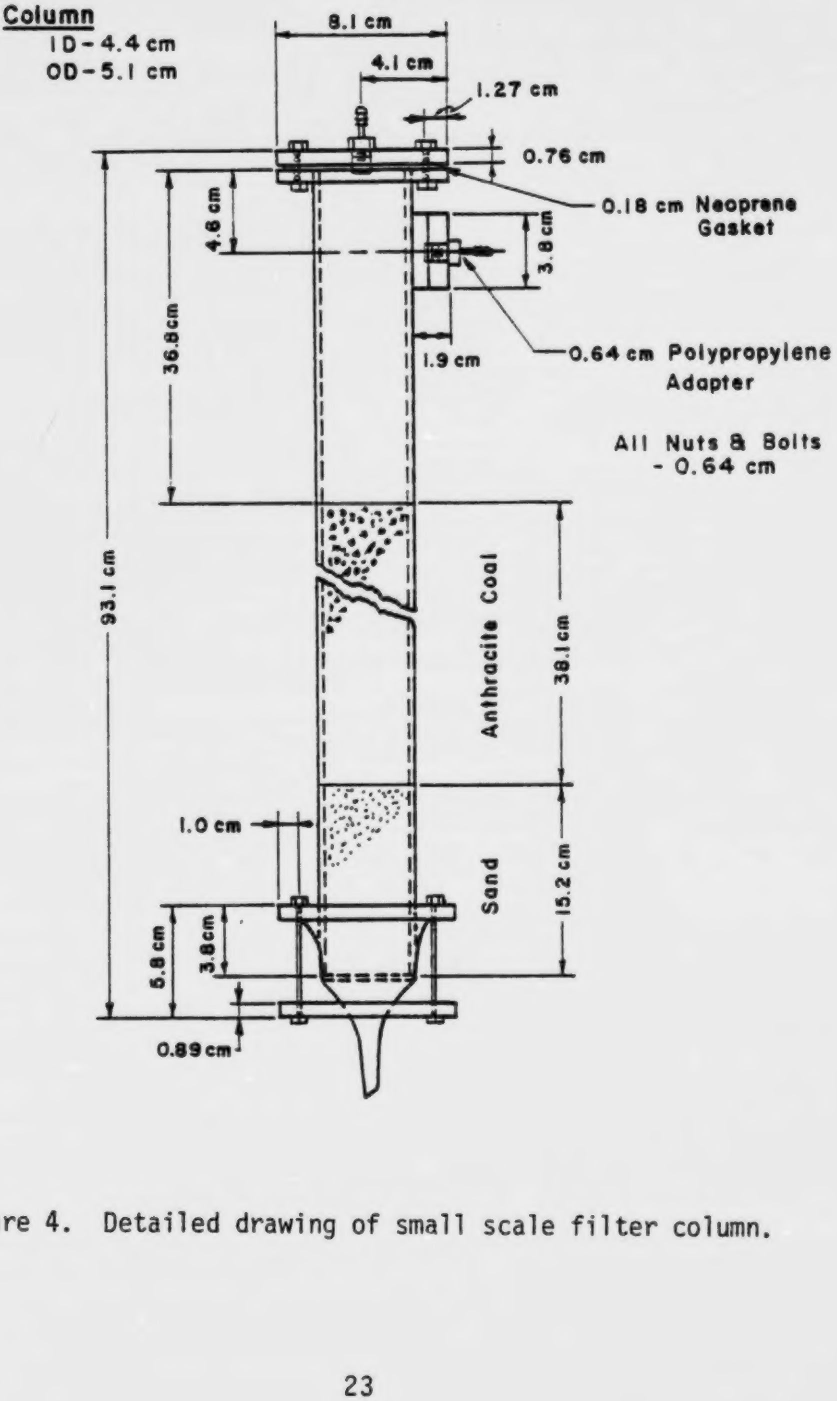

Column
ID-4.4 cm
OD-5.1 cm
8.1 cm
4.1 cm
1.27 cm
0.76 cm
0.18 cm Neoprene Gasket
4.6 cm
3.8 cm
36.8 cm
1.9 cm
0.64 cm Polypropylene Adapter
All Nuts & Bolts - 0.64 cm
93.1 cm
Anthracite Coal
38.1 cm
1.0 cm
Sand
15.2 cm
5.8 cm
3.8 cm
0.89 cm

Figure 4. Detailed drawing of small scale filter column.

(2) Raw water flow was checked initially by volumetric measurements. Filter effluent flow rates were checked several times during the course of an experiment.

(3) If desired, pH was adjusted as described in the subsection on the raw water pumping system.

(4) In a few experiments, the filter media was pre-coated with polymer. This was accomplished by filling the filter bed with a concentrated polymer solution of 500 mg/L. After a 10 minute period, the bed was rinsed with distilled water for 5 minutes in the backwash flow mode at a rate of 49 m/hr (20 gpm/ft^2).

(5) The coagulant feed rate was checked manually to ensure that the proper coagulant dosage would be delivered (see coagulant feed subsection).

(6) For filter runs which utilized flocculation (slow mixing at 20 rpm) the following additional steps were undertaken;
   a) steady state conditions were achieved for the polymer feed by wasting the effluent from the flocculator for three hydraulic detention times,
   b) after the three hydraulic detention times had elapsed, the flocculated suspension was applied to the filter bed.

(7) Time zero for the filter run was considered as the time treated water entered the top of the column.

(8) Samples of 50 mL each were collected every 15 minutes for the first hour of the run and every half-hour for the duration of the filter run. Samples were analyzed for turbitidy, pH, apparent color, and total UV (254 nm). Head loss was also measured.

(9) Filter effluent samples were collected infrequently for NPTOC and TTHMFP - typically, three samples during a filter run.

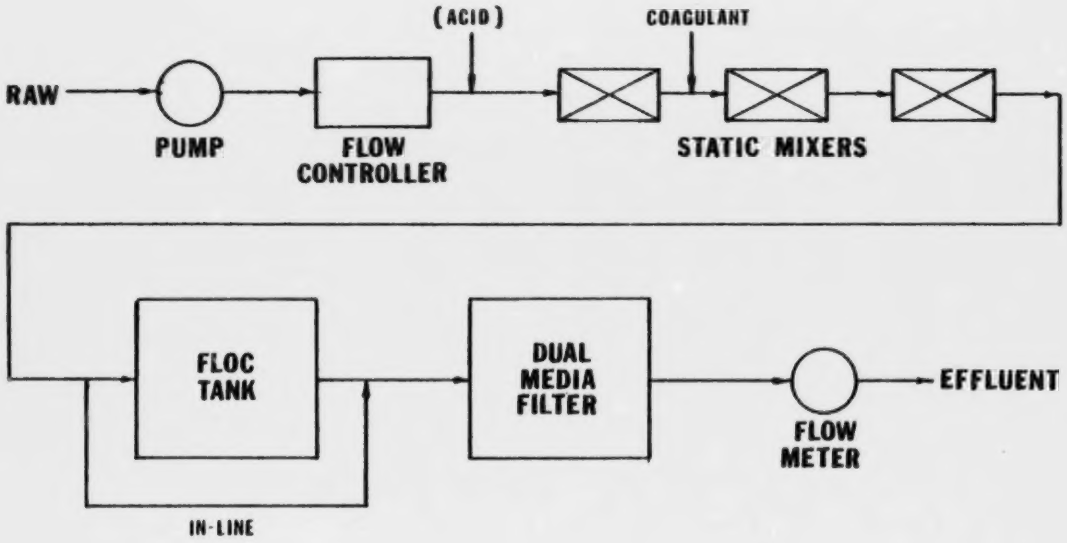
(10) Upon termination of the filter run, the bed was backwashed with distilled water at a rate of 49 m/hr (20 gpm/ft^2) for 15 minutes.

Large Scale Pilot Plant

Description--

The large scale pilot plant was obtained from EPA (Drinking Water Research Div., Cinc., Ohio) for use in this research for the period June 1981 to July 1982. The pilot plant was manufactured by Neptune Microfloc Inc. and is a WB-27, referred to here as simply Waterboy. A schematic of the flow through the pilot plant when operated in either the in-line direct filtration mode or direct filtration with flocculation is presented in Figure 5. Dimensions are given in Table 6, while hydraulic data and filter media specifications are summarized in Tables 7 and 8. As was the case in the small scale pilot filters, the filter media materials were obtained from Unifilt Corp.

The Waterboy was used at both Canton, N.Y. and Oneida, N.Y.. At Canton the Waterboy was set up outdoors on the grounds of the Canton Water



RAW
PUMP
FLOW CONTROLLER
(ACID)
COAGULANT
STATIC MIXERS
FLOC TANK
IN-LINE
DUAL MEDIA FILTER
FLOW METER
EFFLUENT

Figure 5. Process schematic of Waterboy pilot plant.

TABLE 6. WATERBOY GROSS DIMENSIONS

Unit	Length	Width or Diameter	Depth	Volume
In-line Mixers plus Piping	177.8 cm	5.08 cm	NA	3596 cm^3
Flocculation Chamber	62.9 cm	57.2 cm	154.9 cm	0.577 m^3
Filter Box	61.0 cm	61.0 cm	218.4 cm	0.813 m^3
Backwash Water Tank	NA	1.82 m	1.82 m	4.73 m^3

NA not available

Filtration Plant. Water was pumped from the Grasse River to the pilot plant. A coarse screen was placed over the intake to prevent sticks, leaves and debris from entering the pilot plant. At Oneida, the Waterboy was set up in the parking lot of the Oneida Water Treatment Plant. Raw water, from Glenmore Reservoir, was obtained from a nearby fire hydrant which taps off the raw water supply line to the actual treatment plant.

Additional head was provided for the water entering the pilot plant by two electric pumps in series (Goulds Model 3642). A Kates Model C2FA1-1 flow controller was used to regulate the flow. If pH adjustment of the raw water was desired, diluted hydrochloric acid was added at a chemical addition port following the flow controller. A four channel peristaltic pump (Buchler Instruments, Model 2-6150) was used to feed the acid.

The water then flowed to a series of three in-line tubular static mixers (Kenics Corp.) for rapid mixing. Each static mixer was 5.1 cm ID and 45.7 cm long. The total detention time through all three mixers depended on the flow rate, but was less than 7.1 seconds for all experiments. Velcoity gradients (G) of 595-3174 sec^{-1} were calculated depending on the flow rate and temperature. Specific values are listed in Section 7 for each experiment. Calculations were based on data supplied by Kirmeyer (1979) - see Appendix B for methods.

When polymers were used as the primary coagulant, they were added at a chemical addition port between the first and second static mixers. When alum was used, it was added ahead of the first static mixer. If a polymer filter aid was used, it was fed into the pipe just ahead of the filter box. Peristaltic pumps (Scientific Industries Model 203 or Buchler Model 2-6250) were used to feed the diluted coagulants at flow rates up to 13 mL/min.

The pilot plant was operated in both the in-line mode (water by-passed

TABLE 7. WATERBOY HYDRAULIC CONDITIONS

Flow (L/s)	Filtration Rate (m/hr)	Detention Times In-Line* (min)	Detention Times Flocculation+ (min)
0.50	4.88	14.6	33.0 (18.4)‡
1.01	9.76	7.2	16.4 (9.2)
1.45	14.03	5.1	NA
1.51	14.64	4.8	11.0 (6.1)

NA not applicable

* Sum of static mixers, piping, and filter box above media

+ Sum of static mixers, piping, flocculation tank, and filter box above media

‡( ) detention time for flocculation tank only

Table 8. WATERBOY FILTER BED DATA

Filter Area	0.372 m^2
Filter Media Depth	50.8 cm anthracite 25.4 cm sand
Filter Media Effective Size	1.0-1.2 mm anthracite 0.45-0.55 mm sand
Filter Media Uniformity Coefficient	1.33 anthracite 1.49 sand

the flocculation tank) or in the direct filtration with flocculation mode. In the in-line mode, destabilized particles can flocculate after coagulant addition in the static mixers, piping, and in the water column above the filter media. The theoretical mean hydraulic detention times in the static mixers and piping are negligible compared to the detention times in the filter box. These times are summarized in Table 7. In the direct filtration with flocculation mode the water passed through a flocculation tank with detention times of 6.1 to 18.4 min depending on the flow rate - see Table 7. Total detention times including static mixers, piping, flocculation tank, and filter box above media are also shown in the table. The flocculation tank contained a vertical shaft, picket fence paddle-type flocculator driven by a variable speed motor. Velocity gradients varied depending on the experiments and are presented in Section 7. The calculated values were based on information provided by Kirmeyer (1979) as outlined in Appendix B.

A dual media filter was used. Media specifications are listed in Table 8. Figure 6 shows a cross-section of the filter and the arrangement of five manometer taps. An automatic float valve was used to prevent inadvertent draining of the filter box in the event that raw water feed was interrupted. The filtered water was pumped from the bottom of the filter box through a flow meter for checking the flow rate, and then to waste. Backwashing was performed by upflow pumping of water through the filter bed. Treated water from the Oneida or Canton water systems was used for backwashing.

Waterboy Filter Experiments--

Chemical feed rates were determined by mass balance calculations. These rates were checked manually prior to the start of each filter experiment and periodically during the experiment. They were checked by measuring the volume of chemical delivered to a graduated cylinder for a known time. As an additional check the total mass of chemical used during the course of a filter experiment was also determined.

Valves were checked prior to the start of the experiment to ensure that the pilot plant was operating in the desired mode. "Time zero" was noted when effluent was pumped from the bottom of filter, as controlled by a float switch. The flow rate was then checked on the effluent flow meter and adjusted, if necessary.

For NPTOC and TTHMFP, raw water samples were collected at the start of the filter experiment. Filter effluent sampling for NPTOC and TTHMFP was infrequent; two to five samples each were collected depending on the length of the filter run. These samples were hand-carried to the environmental engineering laboratory at Clarkson for analysis.

Raw water temperature, turbidity, pH, apparent color, and total UV (254 nm) absorbance were measured on-site at the time of sample collection. These parameters were measured several times for the raw water during the course of a filter run. Filter effluent samples for turbidity, pH, apparent color, total UV (254 nm) were analyzed immediately on-site. Samples were collected at 30 minute or one hour intervals depending on filter performance and length of the particular filter run. Head loss across the bed was measured at each sampling time. At the start of the run, or after a change in pH or coagulant

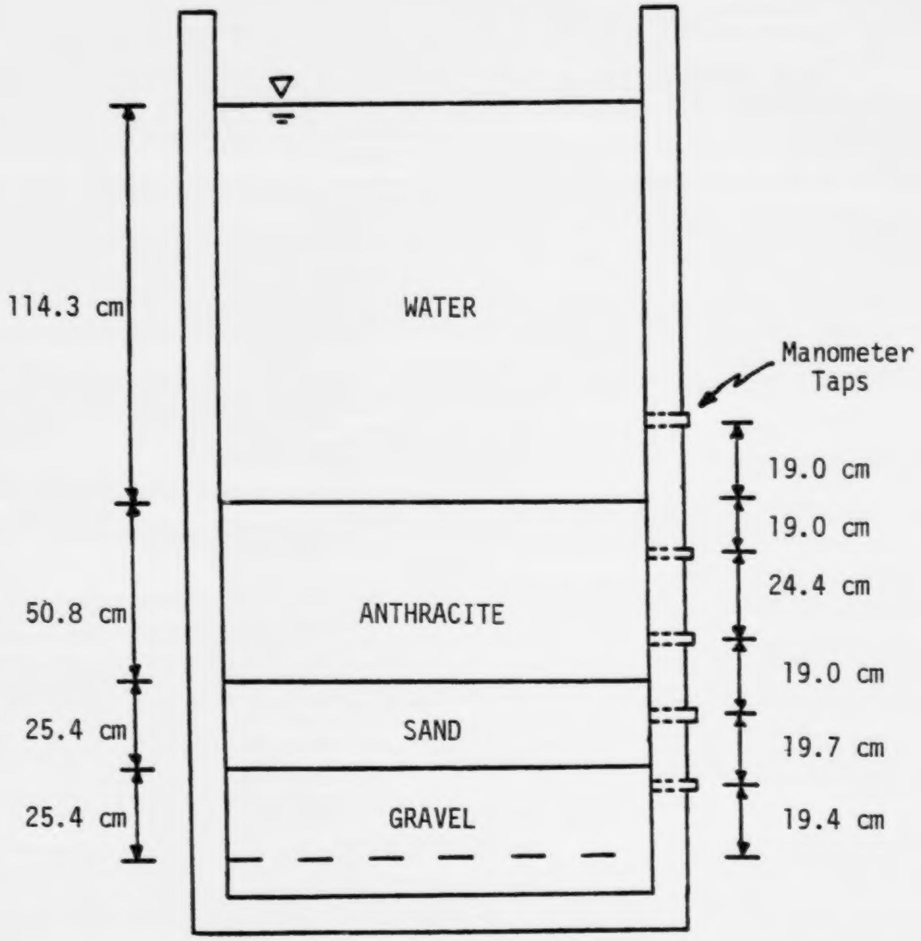

114.3 cm
WATER
Manometer Taps
19.0 cm
19.0 cm
24.4 cm
50.8 cm
ANTHRACITE
19.0 cm
25.4 cm
SAND
19.7 cm
25.4 cm
GRAVEL
19.4 cm

Figure 6. Waterboy pilot plant filter box cross-section.

dosing, sampling was every 15 minutes for an hour.

ANALYTICAL METHODS

The methods used generally followed those specified in Standard Methods (APHA, 1980). Exceptions are spelled out. In addition to following approved methods our laboratory participated in a quality assurance performance evaluation in conjunction with EPA's Environmental Monitoring and Support Laboratory (Cincinnati, Ohio). Unknowns for analysis of turbidity, free residual Cl_2, TOC, and THMs were sent to our laboratory. The results are reported here.

Trihalomethanes

Trihalomethanes were measured by gas chromatographic analysis using the liquid/liquid extraction method (Federal Register, 1979; supplement to 15th edition of Standard Methods - APHA, 1980). Samples which had been stored in the refrigerator were removed from the refrigerator and allowed to warm to room temperature. A 5 mL sample was extracted with 1 mL of methylcyclohexane in a precombusted 7 mL screw cap septum vial (Pierce Chemical Co.). The bottle was capped (TFE faced septa) and agitated for 1 minute, and then allowed to separate into two distinct phases. A 10 μL syringe (Hamilton Co.) was inserted through the septum and a 3 μL sample was taken from the upper phase. Analysis was performed on a Varian Model 3700 gas chromatograph. Operating conditions are summarized in Table 9.

Only two trihalomethanes, chlorofrom ($CHCl_3$) and bromodichloromethane ($CHBrCl_2$) were detected in samples in this study. Standards and standard curves were prepared according to EPA procedures (Federal Register, 1979). The liquid/liquid extraction method has a detection limit for each species of 0.5 μg/L.

In order to ensure that the gas chromatograph was operating properly and that analytical techniques were reproducible, samples of Potsdam tap water were used as internal laboratory controls. THMs were measured on these controls on a daily basis prior to measurements of actual samples. An example of results from one of these laboratory control studies follows. A sample was collected from a tap in the environmental engineering laboratory on February 19, 1980. 13 dechlorinated aliquots were stored headspace free at 4°C. The aliquots were periodically analyzed for $CHCl_3$ over a one year period. The results are presented in Figure 7. They show good reproducibility with a mean $CHCl_3$ concentration of 103.7 μg/L and a standard deviation of 3.4 μg/L. The results also indicate that quenched samples can be stored for a year.

Non-Purgable Total Organic Carbon

Prior to analysis, stored samples were removed from the regrigerator and allowed to warm to room temperature. Samples were then sparged with CO_2 free air (Matheson Gas Products) for a minimum of 5 minutes. Analysis was done with a Beckman 915B Total Organic Carbon Analyzer (low level, high

TABLE 9. OPERATING CONDITIONS OF GAS CHROMATOGRAPH

Carrier Gas	Nitrogen
Carrier Gas Flow Rate	20 mL/min
Column Temperature	67°C
Injector Temperature	180°C
Detector Temperature*	250°C
Column	10% squalane on chromosorb WAW, 80/100 mesh 4 mm ID x 2 m long, glass

* ^{63}Ni Electron Capture Detector

TABLE 10. VISUAL COMPARISON METHOD VERSUS SPECTROPHOTOMETRIC COLOR MEASUREMENTS (Apparent color readings, Grasse River Samples)

Date	Visual Method (Color Units)	Spectrophotometric Method* (Pt-Co Units)
15 July 1981	80	129
17 July 1981	70	115
21 July 1981	80	115
23 July 1981	80	108
27 July 1981	70	115
29 July 1981	70	101
31 July 1981	100	162
11 August 1981	100	170
16 August 1981	100	180
8 October 1981	50	101
Several Dates	0	5-10

* 495 nm, 4 cm cell

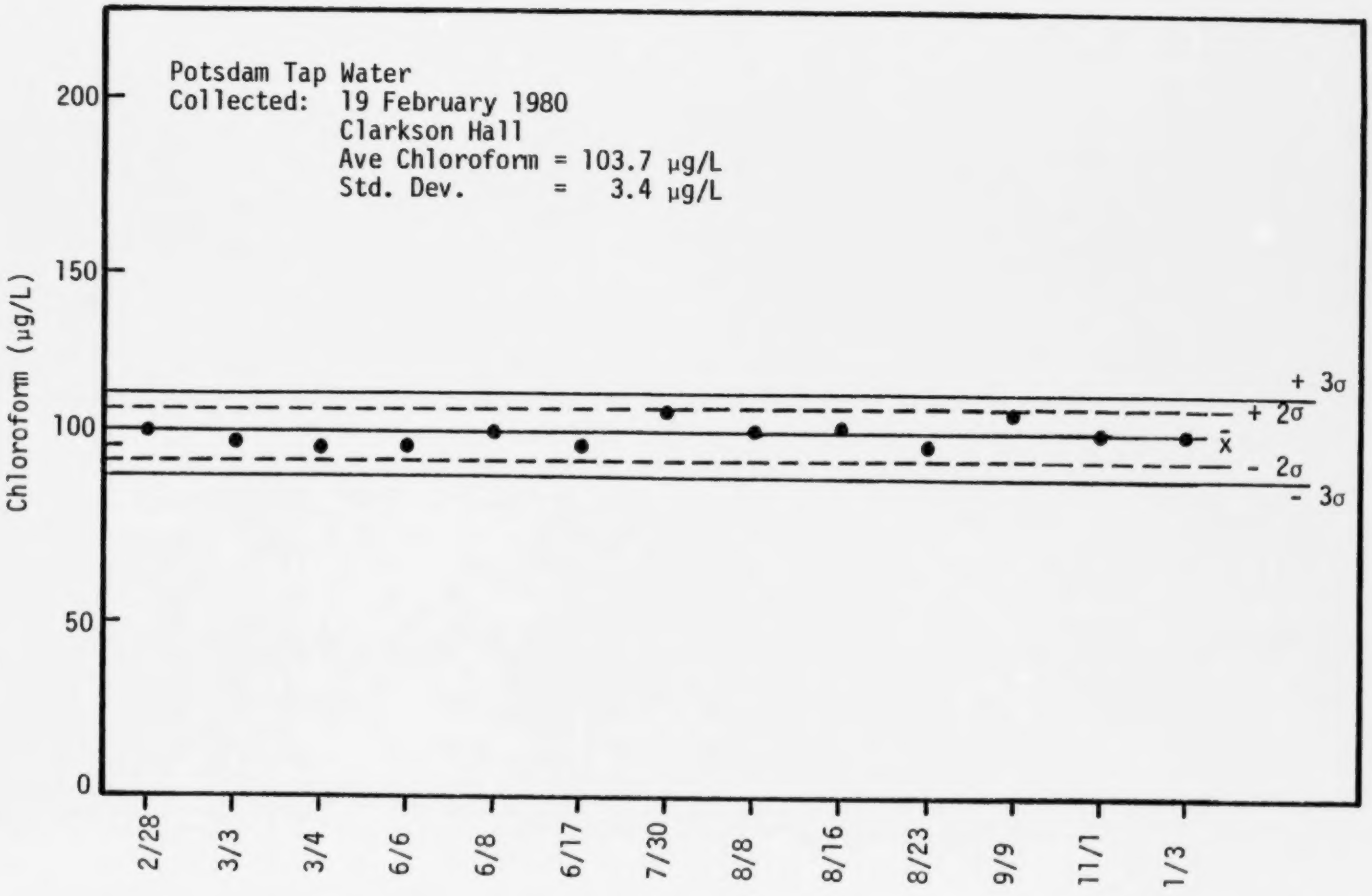


Figure 7. THM quality control results at Clarkson's environmental engineering lab.

sensitivity model). The TOC system employs an integral double beam non-dispersive infrared analyzer, sensitized to detect CO_2 formed by the oxidation of organic carbon.

Standards were prepared from potassium hydrogen phthalate using HPLC water for dilution. Our laboratory ran control samples on a routine basis to establish the reproducibility of the method - i.e., a standard was prepared, broken into aliquots, and the aliquots analyzed over time. For a control sample of about 5 mg/L TOC (average measured value of 4.92 mg/L), a standard deviation of 0.3 mg/L was determined. Most of the TOC measurements in this project were on samples containing 1 to 10 mg/L TOC. Therefore, the control sample was representative for this study and our reproducibility was good.

Turbidity

Three different turbidimeters were employed for this research. A Hach Model 2100A Turbidimeter was used for all jar test experiments conducted in the laboratory at Clarkson. These experiments involved jar testing of the Grasse River. Field measurements at Canton were done using a Hach Model 16800 Portable Turbidimeter. Turbidity measurements associated with Oneida were done in the field using a Hach Model 18900 Ratio Turbidimeter. All three turbidimeters are nephelometers.

Ultraviolet Absorbance

UV absorbance was measured at 254 nm using a 1 cm quartz cell. Low organic water was used as a blank. Analysis was done on a Pye-Unicam SP6-550 UV/VIS Spectrophotometer. Total UV absorbance was measured directly without pH adjustment or filtration. Soluble UV absorbance was measured after filtration through a glass fiber filter (Whatman 934-AH).

For the direct filtration experiments (both small scale and large scale) conducted at Canton, a Beckman DB-G Spectrophotometer was used. Throughout the study, the two instruments were compared and identical results were obtained.

Color

Color measurements were normally made at a wavelength of 420 nm with a 4 cm cell on a Pye-Unicam SP6-550 UV/VIS Spectrophotometer. Apparent color measurements were made on samples in which there was no sample pretreatment (turbidity not removed) nor pH adjustment. True color measurements were made on samples which were filtered through a glass fiber filter (Whatman 934-AH) and then adjusted to pH 11. Color values are based upon platinum-cobalt standards and are reported as Pt-Co units (APHA, 1976).

For the direct filtration experiments (both small scale and large scale) conducted at Canton, the Beckman DB-G Spectrophotometer was used for apparent color measurements. These measurements were made at a wavelength of 495 nm using a 4 cm cell. This wavelength was used in monitoring direct filtration performance for the Grasse River because of the very high yellow-brown color associated with this water.

In water treatment practice, a Visual Comparison Method is normally used to monitor color. This method is not as precise, nor is it as sensitive as spectrophotometric methods. Results in Table 10 compare the Visual Comparison Method with spectrophotometric determination.

Free Residual Chlorine

Different analytical methods were used depending on available sample size, desired accuracy, and the intended use of the results.

For free chlorine determinations associated with laboratory measurements of TTHMFPs and Term TTHMs, a modification of the Stabilized Neutral Orthotolidine (SNORT) method was used (APHA, 1976; Babcock, 1977). The purpose was to determine the presence of free chlorine at the end of a specified reaction period. The modified SNORT method was suitable because small sample volumes can be used. The method involves adding 2 mL of sample to a beaker containing 0.5 mL of neutral orthotolidine reagent, 0.5 mL buffer-stabilizer reagent, and 8 mL of chlorine demand free water. The absorbance is measured spectrophotometrically at 625 nm using a 1 cm path length. The method was periodically checked against the amperometric method. In our measurements of free chlorine for unknowns sent to us by EPA, the modified SNORT method was shown to be accurate (see Table 11).

For field monitoring of the two treatment plants, free residual chlorine was measured either by the amperometric method or the DPD method (APHA, 1976).

Aluminum

Samples of approximately 50 mL were collected in plastic bottles containing sufficient 1:1 nitric acid to acidify the samples to pH 3. Samples were then stored at 4°C until analyzed. Analysis was performed using a Varian Model AA 475 Atomic Absorption Spectrophotometer using a graphite furnace. A detection limit of 6 μg/L was determined.

Quality Assurance Performance Evaluation

Our laboratory participated in a quality assurance performance evaluation in cooperation with EPA's Environmental Monitoring and Support Laboratory (Cincinnati, Ohio). The purpose was to determine our analytical capability to accurately measure the concentrations of several water quality parameters. Sample unknowns were sent to our laboratory by EPA on a periodic basis.

Table 11 summarizes the results for turbidity, free chlorine, TOC and THMs. The table contains our measured values as well as EPA's reported true values and acceptance limits. The true values and acceptance limits were provided by EPA after submission of our results. Acceptance limits for THM measurements are ± 20% of the true values as required by the regulations (Federal Register, 1979). In general our analytical accuracy is excellent

TABLE 11. LABORATORY PERFORMANCE EVALUATION (unknown samples provided by EPA)

Parameter	Samples									
	1	2	3	4	5	6	7	8	9	10
Turbidity (ntu)										
Measured Value	3.85	0.92	4.2	0.62	1.75	6.25	1.05	7.10	1.75	6.20
True Value	4.27	0.82	3.5	0.60	1.75	6.0	1.0	6.7	1.35	5.50
Acceptance Limits	3.3-4.9	0.62-1.1	2.9-4.7	0.34-1.1	1.3-2.1	5.2-6.8	0.63-1.3	6.1-7.3	0.95-1.7	4.6-6.4
Res. Free Cl_2 (mg/L)										
(*) Measured Value	0.9	1.3	0.62	1.82	0.85	1.07	1.05	1.33	0.60	1.45
(+) Measured Value					0.80	1.05	0.98	1.32	0.60	1.45
(‡) Measured Value					0.87	1.35	1.20	1.60	0.70	1.70
True Value	0.897	1.24	0.50	1.29	0.80	1.10	0.95	1.20	0.70	1.51
Acceptance Limits	0.61-1.2	0.91-1.6	0.23-0.85	0.80-1.8	0.37-1.2	0.63-1.6	0.65-1.3	0.87-1.6	0.42-0.99	1.20-1.80
TOC (mg/L)										
Measured Value	49.5	24.0	5.8	90.0	5.4	16.5	35.0			
True Value	52.0	24.5	6.1	91.8	4.8	15.8	36.1			
Acceptance Limits	40.4-63.0	19.4-29.8	4.0-9.4	74.6-107	2.4-7.6	11.0-20.5	26.6-44.7			
$CHCl_3$ (μg/L)										
Measured Value			18.0	45.0	51.5	4.3	19.9	93.7		
True Value			14.9	44.7	76.6	10.2	25.5	102		
Acceptance Limits			12-18	36-54	61-92	8.2-12	20-31	82-120		
$CHBrCl_2$ (μg/L)										
Measured Value			89.0	18.0	88.8	21.7	13.7	56.5		
True Value			94.4	18.9	91.2	22.8	13.7	59.3		
Acceptance Limits			76-110	15-23	73-110	18-27	11-16	47-71		
$CHBr_2Cl$ (μg/l)										
Measured Value			15.0	88.0	57.5	9.0	6.8	77.9		
True Value			11.3	84.8	71.1	11.8	5.92	88.9		
Acceptance Limits			9.0-14	68-100	57-85	9.4-14	4.7-7.1	71-110		

(continued)

TABLE 11. (continued)

Parameter	Samples									
	1	2	3	4	5	6	7	8	9	10
$CHBr_3$ (μg/L)										
Measured Value			29.0	68.0	77.8	31.7	9.2	57.9		
True Value			24.5	61.4	98.7	32.9	11.0	65.8		
Acceptance Limits			20-29	49-74	79-120	26-39	8.8-13	53-79		
TTHM (μg/L)										
Measured Value			151.0	219.0	276	67	49.6	286.0		
True Value			145.1	209.8	337.6	77.7	56.1	316.0		
Acceptance Limits		- - -	120-170	170-250	270-410	62-93	45-67	250-380		

(*) Modified SNORT
(†) Amperometric
(‡) DPD

for all the parameters. It is worth noting that all three of our methods for measuring free chlorine proved accurate.

SECTION 5

CHARACTERIZATION OF RAW WATERS

Raw water samples were collected periodically from the Grasse River and Glenmore Reservoir and used to characterize the concentrations of organic matter in these supplies as measured by NPTOC, TTHMFP (THM precursors), and UV (254 nm) absorbance and to identify seasonsal changes in these parameters. THM precursor concentrations were measured indirectly by determining the 7-day total trihalomethane formation potential (TTHMFP) at pH 7.5 and 20°C. The data were also used to evaluate surrogate parameters for TOC and THM precursors. Emphasis was placed on examining the use of UV (254 nm) as a surrogate parameter. Surrogate parameters are discussed in detail in Section 9 . In this section the two raw water sources are first described, and then the raw water data are presented and discussed. Characterization of the raw water quality for the two water supplies also serves as background for Section 6 (Conventional Water Treatment Plant Performance) and Section 7 (Direct Filtration).

GENERAL DESCRIPTIONS

Grasse River

The Grasse River is a source of drinking water for the Village of Canton, N.Y.. The river is characterized by low levels of turbidity and alkalinity but high levels of color. Data obtained from the Canton Water Filtration Plant for the period 1975-1979 indicate mean weekly values for turbidity and apparent color of 1.8 ntu and 47 Pt-Co units, respectively. As noted in Section 4 the water plant uses the visual comparison method for color which yields much lower values than those based on spectrophotometric measurements. Our own measurements for color reported in this section are spectrophotometric measurements at a wavelength of 420 nm. Typical alkalinities are 20-40 mg/L as $CaCO_3$.

This water supply was selected for this research project because of its features. A low turbidity, highly colored water typical of many supplies found in certain regions of the U.S. such as central and northern New York, New England, and the Pacific Northwest. Another important feature of the site on the Grasse River at Canton, N.Y. is that there are no municipal or industrial wastewaters being discharged to the river upstream. Consequently, the organic matter in the river is naturally occurring and high in humic matter which gives the river the characteristic yellow-brown color of colored waters.

Glenmore Reservoir

The Glenmore Reservoir is a protected, upland water supply for Oneida, N.Y.. There are no dwellings or human activity on the watershed. It is located approximately 20 miles north of the city in the southern foothills of the Adirondack Mountains. Data from the City of Oneida were used to determine mean weekly turbidity of 1 ntu (1977-1979) and apparent color of 15 Pt-Co units (1975-1978) by the visual comparison method. It is a soft water with an alkalinity of about 20 mg/L as $CaCO_3$. The water is of such high quality that no treatment was provided by Oneida other than disinfection and pH control until April 1980.

The Glenmore Reservoir was chosen for this study for several reasons. First, it is a protected upland water supply of low turbidity. A protected reservoir of low turbidity makes it representative of many water supplies in the U.S. and a good model for this research. Second, the organic matter in the reservoir would differ from the Grasse River in terms of nature and concentration providing a contrasting system for study. In the case of the Grasse River the organic matter is primarily humic matter. For the Glenmore Reservoir the organic matter would be naturally occurring since there are no dwellings or human activity permitted on the watershed. The organic matter, however, would be not only derived from humic substances washed into the reservoir from the watershed, but also from organic matter produced within the reservoir-algae, algal by-products, and decomposition products. Finally, it will be shown in this section that the concentration of organic matter in Glenmore Reservoir is much lower than the Grasse River. In this research then we have two water supplies where the organic matter and THM precursors are naturally occurring. But in the Grasse River we have a highly colored water with high concentrations of organic matter while in Glenmore Reservoir we have relatively low concentrations of organic matter derived in part from humic matter, but also derived from production of organic matter within the waterbody.

CHARACTERIZATION OF THE GRASSE RIVER

Raw water samples were collected on 57 dates from February 1980 to March 1982. The results are presented in Table 12. This table also identifies dates the Canton Water Filtraiton Plant was monitored for removals of organic matter and THM precursors, and dates direct filtration pilot plant experiments were conducted. These data will be referred to in Sections 6 and 7.

The turbidity and apparent color data are plotted in Figure 8. Turbidity is highest in the summer while color shows a definite seasonal variation with highest values in the summer and lowest in the winter when the Grasse River is ice-covered. Table 13 summarizes the data according to seasons. The Grasse River is a low turbidity water with a mean turbidity from our data of 2.66 ntu. The turbidity remains low and relatively constant most of the year. The highest turbidity was 6.5 ntu which occurred in the summer (8/16/81). Apparent color undergoes a seasonal variation. In the summer the average color was 147 Pt-Co units while in the winter it was only 72 Pt-Co units. Low and high apparent color values were 45 Pt-Co units on 3/23/81 and 228

TABLE 12. RAW WATER CHARACTERISTICS FOR THE GRASSE RIVER

Date	Temp °C	Turb (ntu)	App. Color (Pt-Co)	Tot. UV (254 nm) (/cm)	NPTOC (mg/L)	TTHMFP (µg/L)	Comments†
02/28/80	0.5	1.7	67	0.113	2.75	245	WPM
04/07/80	5.0	2.2	97	0.243	6.3	537	WPM
05/29/80	18.0	1.2	92	0.263	*	564	WPM
07/14/80	21.0	2.7	110	0.431	8.2	650	C01A
07/24/80	22.0	2.3	105	0.300	7.4	670	C03A
07/30/80	23.0	2.0	100	0.458	11.8	743	C05A
08/05/80	23.0	2.3	166	0.470	9.8	732	WPM
08/19/80	19.0	2.2	140	0.540	10.9	689	C09A
10/10/80	14.0	2.4	105	0.350	8.4	626	C11A
10/13/80	11.0	1.3	130	0.355	6.9	612	WPM
10/31/80	12.0‡	1.6	65	0.307	*	*	C13A
12/12/80	5.0	1.5	105	0.305	7.5	541	WPM
01/19/81	6.5‡	2.6	60	0.159	3.5	232	C14A
01/26/81	1.0	2.2	72	0.151	3.2	255	WPM
03/02/81	1.0	1.3	80	0.202	5.5	353	
03/12/81	2.0	2.2	69	0.159	3.7	323	WPM
03/16/81	8.0‡	2.1	50	0.162	3.4	278	C18A
03/23/81	12.0‡	1.5	45	0.150	3.3	266	C20A
04/01/81	4.0	1.8	110	0.254	6.0	439	
04/15/81	5.0	*	72	0.233	5.8	426	
05/07/81	12.2	1.9	86	0.235	5.7	432	WPM
06/18/81	19.0	3.2	153	0.411	7.9	751	WPM
06/22/81	22.0	2.2	102	0.470	8.8	775	C01P
06/25/81	22.0	5.5	197	0.480	8.1	741	C02P
06/30/81	21.0	3.9	168	0.510	10.4	878	C03P
07/02/81	23.0	4.3	145	0.400	8.8	692	C04P
07/08/81	25.0	3.6	136	0.450	8.5	738	C05P
07/13/81	23.5	3.8	115	0.435	8.1	656	C06P
07/15/81	23.5	2.6	129	0.465	9.4	740	C07P
07/17/81	23.0	2.7	115	0.440	8.5	686	C08P
07/21/81	23.5	2.5	115	0.400	8.0	674	C09P
07/23/81	22.0	2.5	108	0.370	7.3	657	C10P
07/27/81	23.5	2.1	115	0.430	8.7	740	C11P
07/29/81	20.0	2.0	101	0.375	8.1	688	C12P
07/31/81	20.0	4.0	175	0.470	10.3	858	C13P
08/04/81	24.0	2.2	102	0.500	11.1	916	C14P
08/11/81	22.5	4.1	170	0.550	12.7	938	C15P
08/13/81	22.0	5.1	202	0.640	14.0	1045	C16P
08/16/81	19.5	6.5	180	0.540	12.1	915	C17P
08/19/81	19.5	2.5	228	0.666	14.7	1108	WPM
09/14/81	14.0	1.9	228	0.618	*	*	
09/17/81	11.0	3.5	216	0.583	12.4	902	

(continued)

TABLE 12. (continued)

Date	Temp °C	Turb (ntu)	App. Color (Pt-Co)	Tot. UV (254 nm) (/cm)	NPTOC (mg/L)	TTHMFP (μg/L)	Comments[+]
09/22/81	14.0	2.4	160	0.446	*	*	
10/08/81	9.0	3.1	101	0.320	8.6	508	
10/15/81	9.0	2.1	120	0.324	6.6	579	WPM
10/20/81	8.5	2.4	80	0.300	6.6	488	
10/22/81	7.0	2.3	90	0.320	7.6	583	
11/09/81	4.0	2.9	103	0.279	7.2	405	
11/24/81	4.0	1.8	105	0.281	6.2	421	
12/10/81	2.5	2.1	87	0.194	3.9	305	WPM
01/04/82	10.0[‡]	3.0	65	0.195	4.9	300	C21A
01/13/82	6.5[‡]	2.2	65	0.205	4.8	376	C23A
01/15/82	0.5	2.0	80	0.197	3.6	297	WPM
01/18/82	6.0[‡]	3.9	73	0.185	4.1	283	C24A
02/17/82	10.0[‡]	3.2	58	0.168	4.1	252	C25A
02/18/82	2.0	2.5	76	0.170	3.5	283	WPM
03/24/82	0.5	3.1	105	0.196	5.6	302	WPM

* Not Available

[+] WPM: Canton Water Plant Monitoring; A designation: small scale pilot plant exp.; P designation: Waterboy exp.; for small scale experiments usually more than one exp. was conducted on the day indicated.

[‡] Water temperature in raw water reservoir for small scale pilot plant experiments.

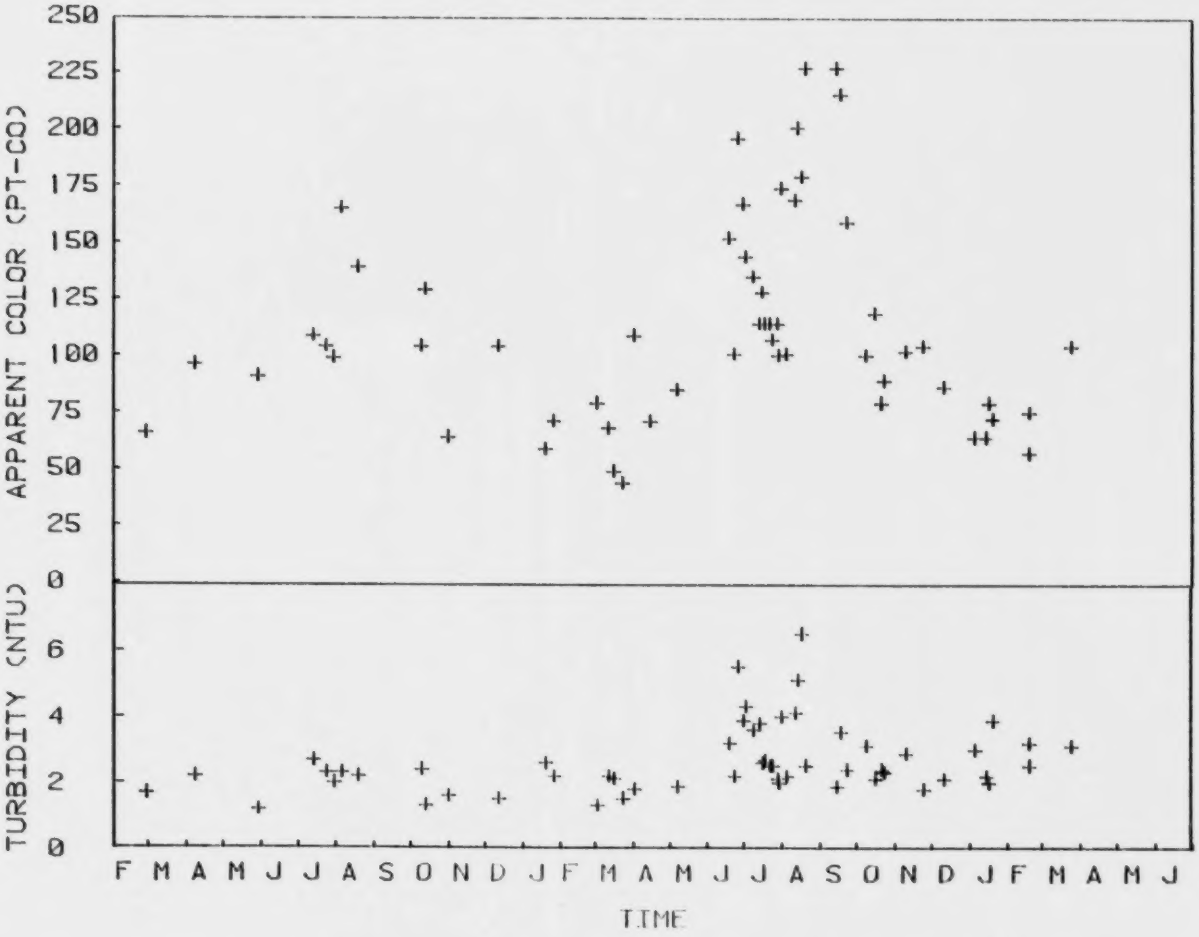


Figure 8. Seasonal variation in color and turbidity for the Grasse River.

TABLE 13. RAW WATER QUALITY FOR THE GRASSE RIVER BY SEASON
(DATA BASE: 2/28/80 - 3/24/82)

Parameter	Spring[*]	Summer	Fall	Winter	All Seasons
Turbidity (ntu)	Mean[+] 1.95 (6) SD 0.66 Range 1.2-3.1	3.13 (27) 1.19 1.9-6.5	2.21 (9) 0.58 1.3-3.1	2.32 (14) 0.69 1.5-3.9	2.66 (56) 1.05 1.2-6.5
App. Color (Pt-Co units)	87 (7) 22 45-110	147 (27) 41 100-228	100 (9) 20 65-120	72 (14) 14 50-105	114 (57) 45 45-228
Total UV (cm^{-1})	0.22 (7) 0.04 0.150-0.263	0.48 (27) 0.08 0.30-0.666	0.32 (9) 0.03 0.279-0.355	0.18 (14) 0.04 0.113-0.205	0.348 (57) 0.144 0.113-0.666
NPTOC (mg/L)	5.4 (6) 1.08 3.3-6.3	9.8 (25) 2.1 7.3-14.7	7.3 (8) 0.88 6.2-8.6	4.2 (14) 1.21 2.75-7.5	7.46 (53) 2.96 2.75-14.7
TTHMFP (µg/L)	424 (7) 110 266-564	783 (25) 127 645-1108	528 (8) 85 405-626	309 (14) 78 232-541	576 (54) 232 232-1108
$CHCl_3$ Yield (µg/mg)	73.0 (6) 10.7 53.1-84.4	79.7 (25) 7.9 62.3-94.3	72.2 (8) 11.9 55.2-87.7	74.1 (14) 8.9 60.1-87.3	76.4 (53) 9.5 53.1-94.3

[*] Grasse River observations: Spring Mar. 23 - May 29; Summer June 18 - Sept. 22; Fall Oct. 8 - Nov. 24; Winter Dec. 10 - Mar. 16

[+] Data include Mean, Standard Deviation, Range, and ( ) no. of observations

Pt-Co units on 8/19/81 and 9/14/81. These data support the general description provided earlier that the Grasse River is a low turbidity, highly colored water. A major discrepancy exists between our color data (spectrophotometric measurements) and Canton water plant records. This is because the Canton plant uses the visual comparison method. A comparison of these methods for Grasse River samples was previously presented in Table 10.

Typical THM formation curves for Grasse River samples are shown in Figure 9. All curves were produced for pH 7.5 and 20°C with free residual chlorine present throughout the reaction period. In this study the 7-day TTHMFP is used as an indirect measurement of the concentration of THM precursors. This figure demonstrates the seasonal variation in THM precursor concentrations.

All of the raw water TTHMFP data as well as NPTOC and UV (254 nm) data are presented in Table 12. These data are plotted in Figure 10 and show a definite seasonal variation. Table 13 shows that the highest UV (254 nm), NPTOC, and TTHMFP occur in summer with mean summer values of 0.48 cm^{-1}, 9.8 mg/L, and 783 μg/L, respectively. The lowest values occur in winter with mean values of 0.18 cm^{-1} for UV (254 nm), 4.2 mg/L for NPTOC, and 309 μg/L for TTHMFP. As expected these measurements of organic matter and THM precursors follow the same seasonal trend as apparent color.

Many people in the water supply field believe that the poorest water quality for water supplies similar to the Grasse River occurs in the autumn during leaffall or in the spring during the spring snowmelt. An important finding of this work is that the worst water quality in terms of organic matter occurs in the summer, particularly late summer.

Chloroform yield data are presented in Table 13. $CHCl_3$ yields are defined as the ratio of $CHCl_3$ formed during the 7-day TTHMFP reaction to the NPTOC originally present in the raw water sample. The data are pretty constant with a mean of 76.4 μg $CHCl_3$ per mg TOC with a standard deviation of 9.5. No seasonal variation is apparent, which would indicate that the nature of the THM precursor material in the Grasse River is generally the same throughout the year.

CHARACTERIZATION OF THE GLENMORE RESERVOIR

Raw water samples were collected on 44 occasions from February 1980 to June 1982 to characterize the water quality of the reservoir. The results are presented in Table 14. This table also shows dates the Oneida Water Treatment Plant was monitored for removals of organic matter and THM precursors, and dates direct filtration pilot plant experiments were performed. These data will be referred to in Sections 6 and 7.

The apparent color and turbidity data are plotted in Figure 11. A clearly defined seasonal trend in turbidity is evident, with the lowest values occurring during the winter months when the Glenmore Reservoir is ice-covered, and the highest values occurring during the summer and early fall months.

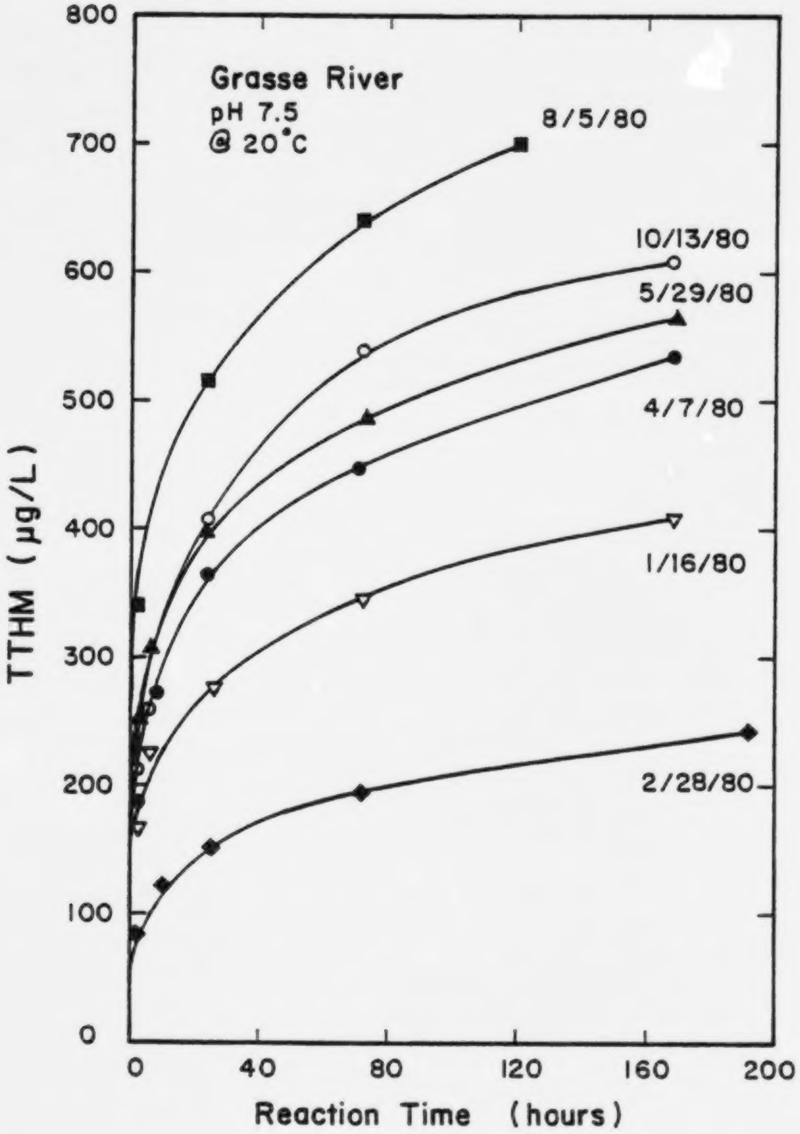


Figure 9. Typical trihalomethane formation potential curves for the Grasse River.

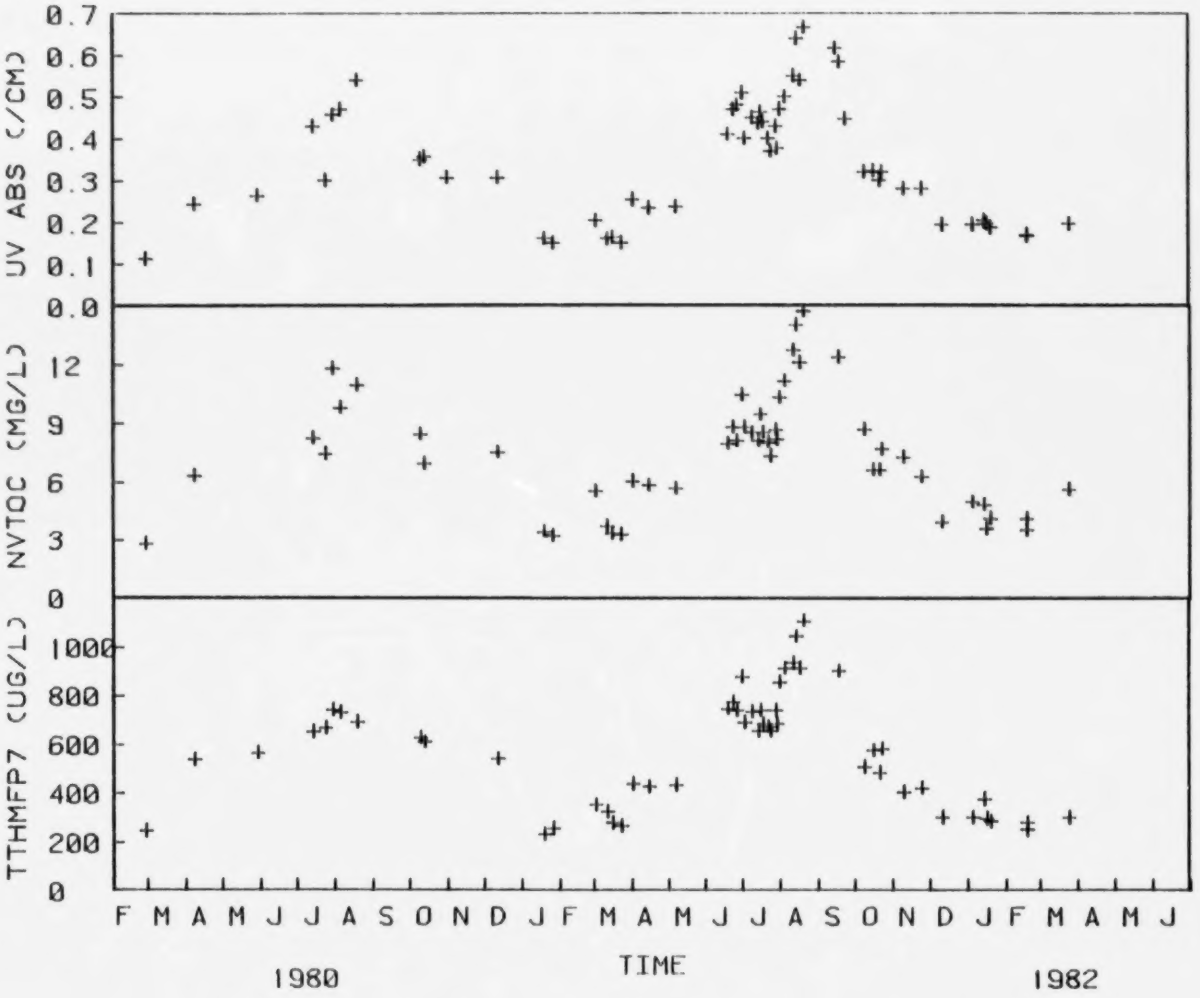


Figure 10. Seasonal variation in UV (254 nm), NVTOC, and TTHMFP for the Grasse River.

TABLE 14. RAW WATER CHARACTERISTICS FOR THE GLENMORE RESERVOIR

Date	Temp °C	Turb (ntu)	App. Color (Pt-Co units)	Tot. UV (254 nm) (/cm)	NPTOC (mg/L)	TTHMFP (µg/L)	Comments+
02/25/80	2.0	0.55	48	0.087	*	253	
04/10/80	8.0	3.5	97	0.235	*	423	WPM
06/03/80	14.0	1.7	81	0.174	*	327	WPM
07/21/80	18.0	2.2	30	0.196	4.0	349	1A
07/22/80	18.0	1.4	43	0.196	4.0	309	2A
09/02/80	21.0	3.0	105	0.225	4.3	*	WPM
10/14/80	12.0	1.7	80	0.212	6.0	288	WPM
12/19/80	3.0	1.0	58	0.132	3.9	261	WPM
01/23/81	3.0	0.61	25	0.097	2.9	204	3A
02/16/81	3.0	0.63	31	0.106	2.6	183	WPM
03/30/81	4.0	0.88	36	0.092	2.8	242	5A
04/20/81	8.5	1.1	57	0.164	3.8	283	WPM
05/17/81	12.0	1.5	55	0.176	6.3	304	8A
05/18/81	12.0	1.6	70	0.194	4.5	318	9A
05/19/81	12.0	1.3	63	0.191	4.2	328	10A
05/20/81	12.5	1.1	68	0.188	5.3	329	WPM
06/09/81	19.0	1.3	*	0.146	4.1	272	11A
06/10/81	19.0	1.7	47	0.157	4.8	266	12A
06/11/81	19.0	1.6	46	0.161	3.3	275	13A
06/25/81	19.0	1.7	72	0.209	6.1	350	WPM
07/19/81	20.0	0.98	48	0.168	*	*	14A
07/20/81	20.0	1.0	56	0.180	4.7	336	15A
07/21/81	20.0	1.4	109	0.160	6.2	380	16A
07/22/81	20.0	2.1	129	0.309	10.6	597	WPM
08/20/81	18.0	1.6	79	0.266	6.1	470	WPM
09/11/81	17.5	2.4	107	0.228	7.8	502	
10/09/81	10.0	1.2	92	0.198	5.1	418	WPM
10/22/81	8.0	0.75	63	0.170	3.7	370	17A
10/23/81	8.0	0.90	75	0.169	4.2	338	18A
11/25/81	6.5	0.75	40	0.146	2.9	275	WPM
01/05/82	3.0	0.74	38	0.105	3.2	175	19A
01/08/82	4.0	0.63	31	0.094	3.5	176	WPM
03/04/82	3.0	0.67	26	0.086	2.0	152	21A
03/06/82	3.0	0.54	22	0.084	2.0	152	WPM
05/06/82	12.0	1.1	37	0.108	3.1	258	2P
05/07/82	12.0	0.78	32	0.115	3.4	263	WPM
05/11/82	12.0	1.4	40	0.125	2.5	252	4P
05/12/82	12.0	1.2	44	0.124	2.6	266	5P
05/14/82	13.0	1.4	46	0.119	2.3	266	6P
05/17/82	13.0	1.1	49	0.120	2.5	261	7P
05/18/82	13.0	1.1	47	0.125	2.9	263	8P
06/12/82	14.0	1.5	73	0.205	4.4	359	14P
06/13/82	14.0	1.6	75	0.195	4.6	363	15P
06/22/82	16.0	1.5	59	0.163	4.1	322	16P

* Not available

+ WPM: Oneida Water Plant Monitoring; A designation: small scale pilot plant exp.; P designation: Waterboy exp.; for small scale experiments usually more than one exp. was conducted on the day indicated.

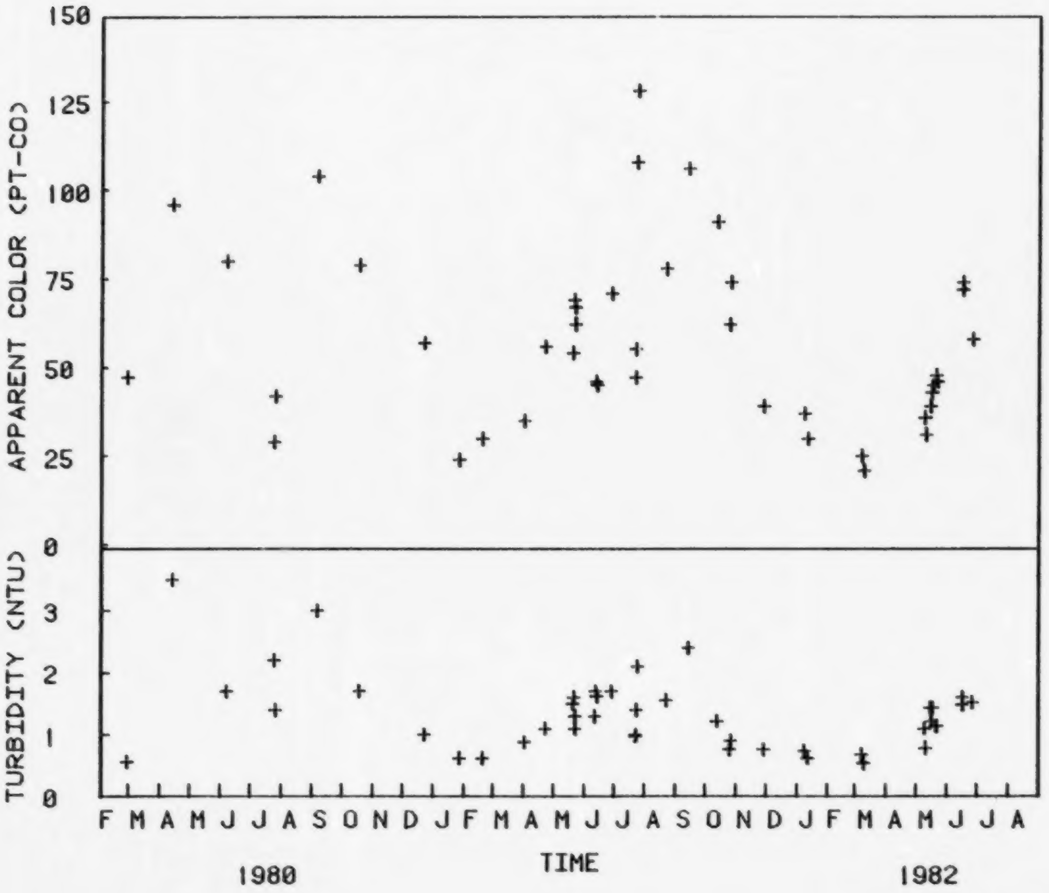


Figure 11. Seasonal variation in color and turbidity for the Glenmore Reservoir.

Apparent color follows a similar trend. Table 15 summarizes the data according to seasons. The lowest and highest turbidity measured were 0.54 ntu on 3/6/82 and 3.5 ntu on 4/10/80, respectively. Low and high apparent color values were 22 Pt-Co units on 3/6/82 and 129 Pt-Co units on 7/22/81. Mean turbidity and apparent color values were 1.33 ntu and 59 Pt-Co units, respectively (see Table 15). These data agree with water plant records which were referred to earlier in the general description of the Glenmore Reservoir.

Plots of total UV absorbance (254 nm), NPTOC, and TTHMFP are presented in Figure 12. A definite seasonal trend exists with low values when the reservoir is ice-covered and high values during the summer and early fall. Low and high total UV (254 nm) values were 0.084 cm^{-1} on 3/6/82 and 0.309 cm^{-1} on 7/22/81, respectively. Low and high NPTOC were 2.0 mg/L observed on two occasions (3/4/82 and 3/6/82) and 10.6 mg/L on 7/22/81. Low and high TTHMFP values were 152 μg/L observed on two occasions (3/4/82 and 3/6/82) and 597 μg/L observed on 7/22/81. Mean values for total UV absorbance, NPTOC, and TTHMFP were 0.161 cm^{-1}, 4.2 mg/L, and 304 μg/L, respectively.

Chloroform yield data ranged from a low of 46.5 μg $CHCl_3$ per mg TOC on 10/14/80 to a high of 113.8 μg $CHCl_3$ per mg TOC on 5/14/82. The average chloroform yield for 39 samples was 73.9 μg $CHCl_3$ per mg TOC with a standard deviation of 16.2 μg $CHCl_3$ per mg TOC. Seasonal values are presented in Table 15, but the standard deviations are too high to definitely establish trends. The high standard deviations may be due to fluctuations in the nature of the chloroform precursors present. A wide range of chloroform precursors may be present in the reservoir such as humic materials, organic nitrogen compounds, algae, and by-products of algae.

TABLE 15. RAW WATER QUALITY FOR THE GLENMORE RESERVOIR BY SEASON
(DATA BASE: 2/25/80 - 6/22/82)

Parameter	Spring[*]	Summer	Fall	Winter	All Seasons
Turbidity (ntu)	Mean[+] 1.46(20)	1.77 (10)	1.06 (5)	0.69 (9)	1.33 (44)
	SD 0.54	0.64	0.40	0.15	0.62
	Range 0.78-3.5	0.98-3.0	0.75-1.7	0.54-1.0	0.54-3.5
App. Color (Pt-Co units)	57 (19)	78 (10)	70 (5)	35 (9)	59 (43)
	17	33	20	12	25
	32-97	30-129	40-92	22-58	22-129
Total UV (cm^{-1})	0.16 (20)	0.21 (10)	0.18 (5)	0.10 (9)	0.161 (44)
	0.04	0.05	0.03	0.01	0.05
	0.108-0.235	0.16-0.309	0.146-0.212	0.084-0.132	0.084-0.309
NPTOC (mg/L)	3.8 (18)	6.0 (9)	4.4 (5)	2.9 (8)	4.2 (40)
	1.09	2.15	1.21	0.67	1.7
	2.3-6.3	4.0-10.6	2.9-6.0	2.0-3.9	2.0-10.6
TTHMFP (µg/L)	300 (20)	412 (8)	338 (5)	200 (9)	304 (42)
	46	101	59	43	90
	252-423	309-597	275-418	152-261	152-597
$CHCl_3$ Yield (µg/mg)	79.4 (18)	67.9 (8)	78.9 (5)	64.6 (8)	73.9 (39)
	17.1	10.8	19.7	12.2	16.2
	47.6-113.8	55.5-86.0	46.5-97.1	49.2-84.6	46.5-113.8

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[*] Glenmore Reservoir observations: Spring Apr. 10 - June 22; Summer June 25 - Sept. 11; Fall Oct. 9 - Nov. 25; Winter Dec. 19 - Mar. 30

[+] Data include mean, standard deviation, range, and ( ) no. of observations

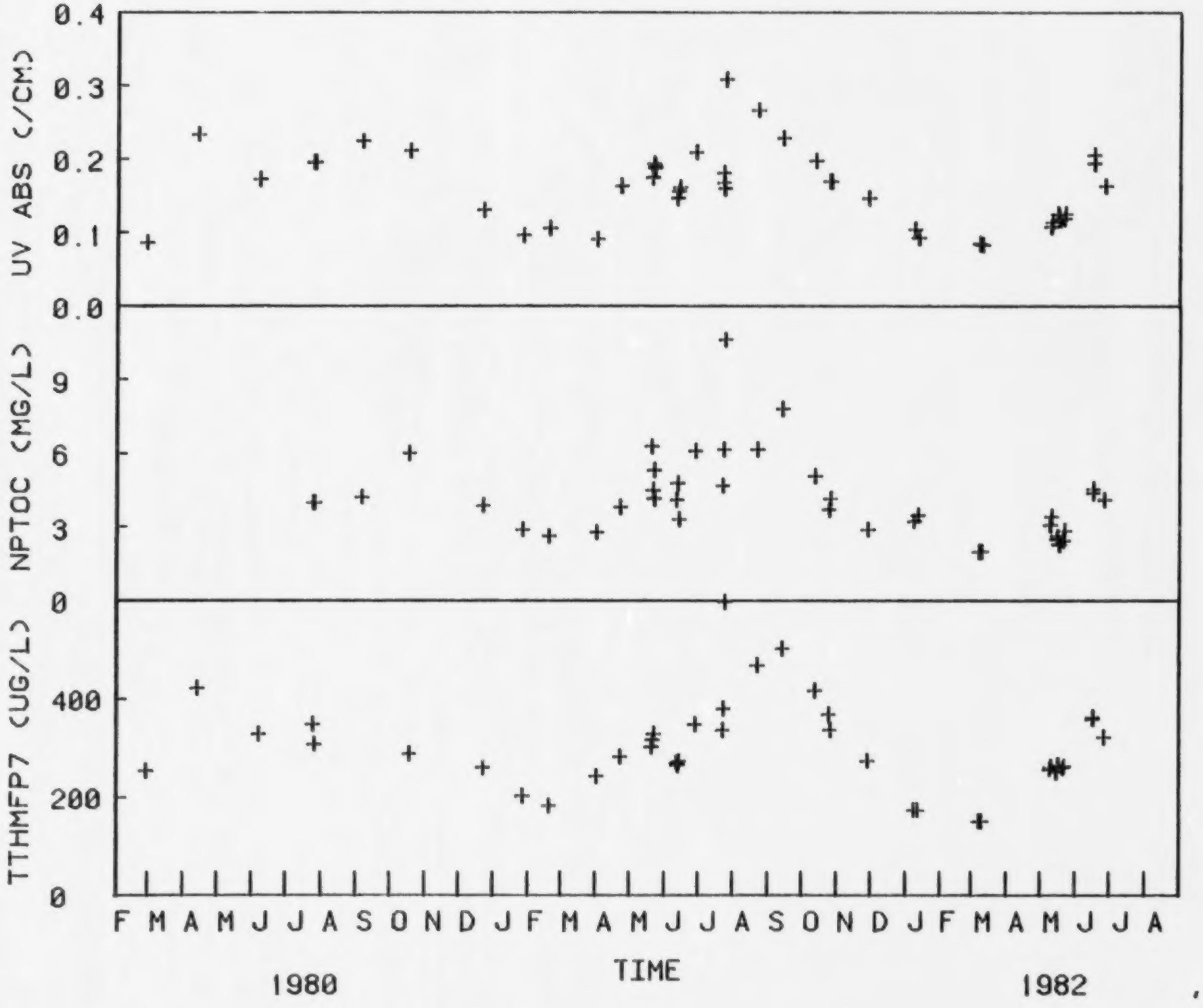


Figure 12. Seasonal variation in UV (254 nm), NPTOC, and TTHMFP of the Glenmore Reservoir.

SECTION 6

CONVENTIONAL WATER TREATMENT PLANT PERFORMANCE

This section describes the results of the monitoring studies of the Canton, N.Y. and Oneida, N.Y. water treatment plants. These studies were designed to evaluate the removals of NPTOC and THM precursors (TTHMFP) by conventional type water treatment plants. THM formation through the water plants was also investigated. In Section 8 conventional water treatment plant performance is compared with direct filtration.

CANTON WATER TREATMENT PLANT EVALUATION

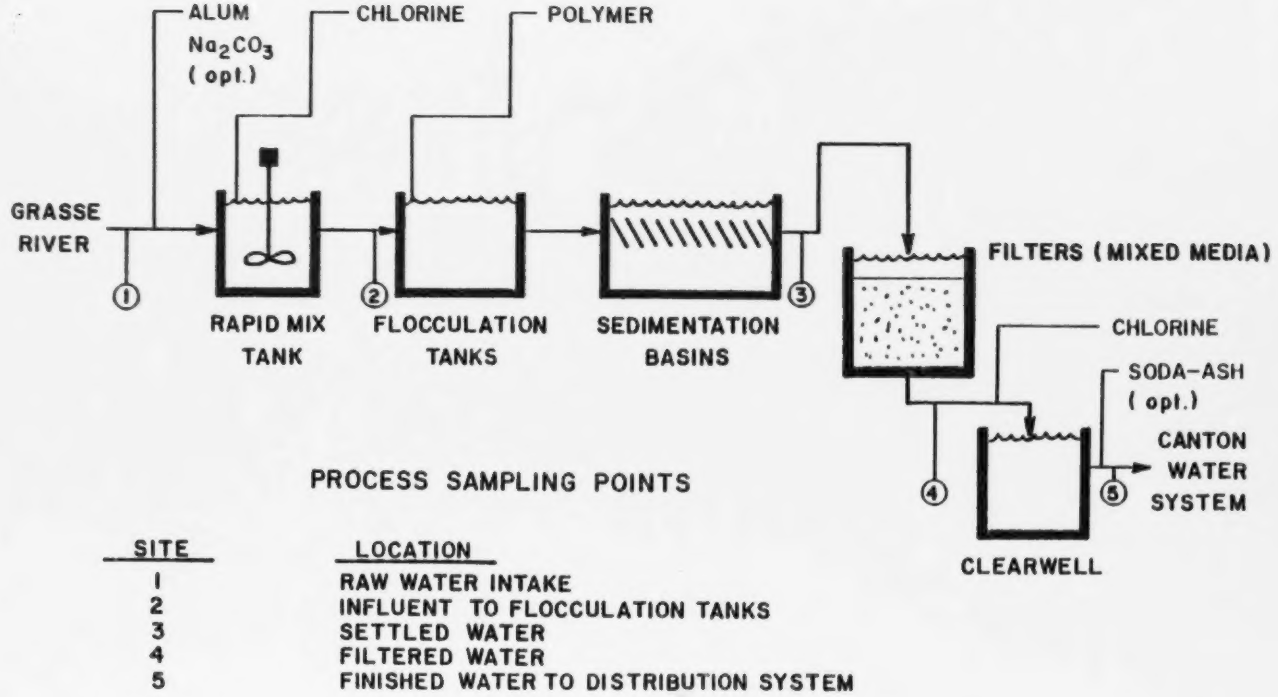
Plant Description

The water treatment plant at Canton was opened in 1973. It is a conventional water treatment plant as shown in Figure 13 - i.e., processes of coagulation-flocculation, sedimentation, and filtration. But it does use tube settlers which makes it different from traditional conventional plants, which use settling basins with long detention times.

Alum is used for coagulation, and a nonionic polymer (Calgon 233E) is used as a coagulant aid. The polymer is added at a point where the water enters the flocculation basins. The plant has tube settlers followed by mixed media filters. Pre- and post-chlorination are normally practiced. For prechlorination, the chlorine is added to the rapid mix tank. For post-chlorination, the chlorine is applied at a point between the filters and the clearwell.

An important distinguishing characteristic of this plant when compared with traditional conventional plants is the hydraulic detention time through the plant. Due to the tube settlers, the detention time is short. For a flow of 11.4 ML/d (3 MGD) which is a normal operating flow rate, the detention time, excluding the clearwell, is only about 1 hour.

Early in the study, samples were collected at the sampling locations indicated in Figure 13. Sampling point 2 (rapid mix effluent) was eliminated after December 12, 1980. In addition Inst THMs were also measured on samples from Canton's distribution system. These samples were normally collected on the dates that the plant was being monitored. Two distribution sampling points were chosen; one at the Canton Bakery (Point 6) on highway U.S. 11 and the other at the Canton municipal wastewater treatment plant (Point 7, far end of the distribution system). These sites were chosen


ALUM
Na_2CO_3
(opt.)
CHLORINE
POLYMER
GRASSE RIVER
①
②
③
④
⑤
RAPID MIX TANK
FLOCCULATION TANKS
SEDIMENTATION BASINS
FILTERS (MIXED MEDIA)
CHLORINE
SODA-ASH (opt.)
CANTON WATER SYSTEM
CLEARWELL

PROCESS SAMPLING POINTS

SITE	LOCATION
1	RAW WATER INTAKE
2	INFLUENT TO FLOCCULATION TANKS
3	SETTLED WATER
4	FILTERED WATER
5	FINISHED WATER TO DISTRIBUTION SYSTEM

Figure 13. Process schematic of the Canton Water Filtration Plant.

because the water plant operators use these sites for other distribution analyses, and because their location dictates reasonably long detention times for the distribution system.

Canton Performance

Monitoring results are presented and discussed in this section. A total of 16 monitorings were conducted between February 1980 and March 1982. Monitoring dates and the associated raw water data are shown in Table 12. The monitoring program was directed at examining the removal of organic matter and THM precursors by the Canton plant and on examining THM formation through the plant.

This section is organized as follows. First, three monitorings are described in detail since they illustrate plant performance as influenced by raw water THM precursor concentration (or TOC), temperature, pH, and chlorination practice. Next, plant performance for the 16 monitoring dates is summarized and discussed in terms of the efficiency of coagulation-flocculation-sedimentation vs. coagulation-flocculation-sedimentation-filtration. The effect of temperature on performance is included in this discussion. Finally, THMs in the Canton distribution system are discussed.

Illustrations of Plant Performance--

Low TOC and low TTHMFP--The results of the 1/26/81 monitoring are shown in Figures 14 and 15. On this date the Grasse River was ice-covered, and thus had low water concentrations of NPTOC (3.2 mg/L) and THM precursors (TTHMFP of 255 μg/L). An alum dosage of 40 mg/L was used for coagulation followed by 0.6 mg/L of the coagulant aid (nonionic polymer). The process detention times are shown at the top of the figures. Note again that the plant hydraulic detention time is short. The total detention time at 11.4 ML/d (3 MGD), excluding the clearwell, is 60 min. On this date the plant used prechlorination and postchlorination dosages of 1.3 mg/L.

Examining plant performance (raw water vs. filter effluent) shows good removals for UV absorbance (67%), NPTOC (60%), and Term TTHM (69%). The data, especially the TOC and turbidity data, show that the filters do most of the work. Sedimentation of floc is poor due to the low water temparature of 1-2.5°C. The effect of temperature on performance will be discussed in detail later.

Although plant records indicated a prechlorination dosage of 1.3 mg/L, no free chlorine residual was found ahead of the clearwell as shown in Figure 15. A postchlorination dose of 1.3 mg/L resulted in a free chlorine residual in the clearwell. These chlorination conditions coupled with the low water temperature (1-2.5°C) and relatively low concentration of THM precursors resulted in low THM formation through the plant - Inst TTHM of 10 μg/L prior to the clearwell and 25 μg/L in the water being pumped from the clearwell.

High TOC and high TTHMFP--The Canton plant was monitored on 8/19/81 when the NPTOC (14.7 mg/L) and TTHMFP (1108 μg/L) were the highest observed concentrations during the raw water characterization study - see Figures

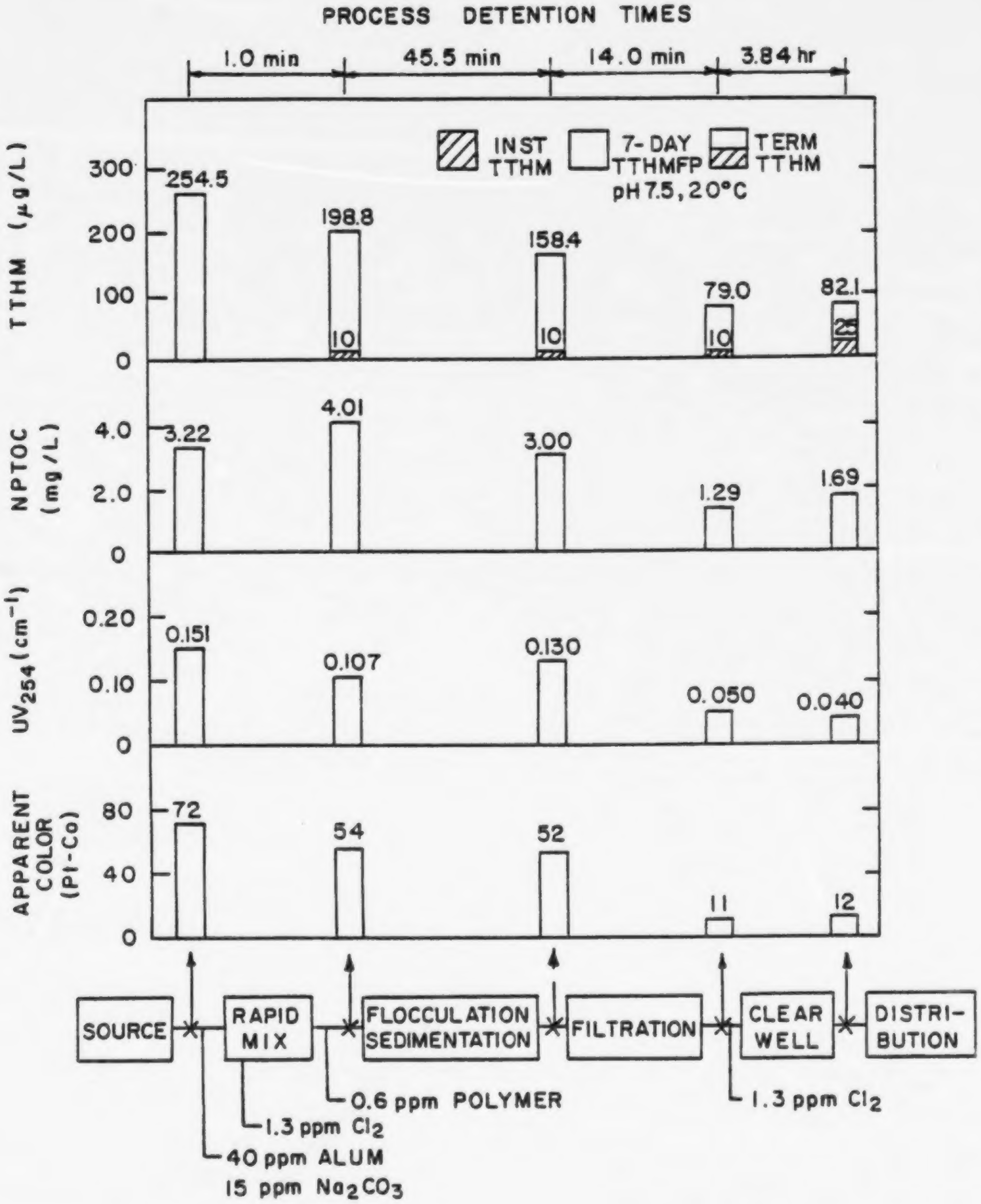


Figure 14. Monitoring results for the Canton water plant on 1/26/81 (Flow 11.4 ML/d (3 MGD), 1-2.5°C), part A.

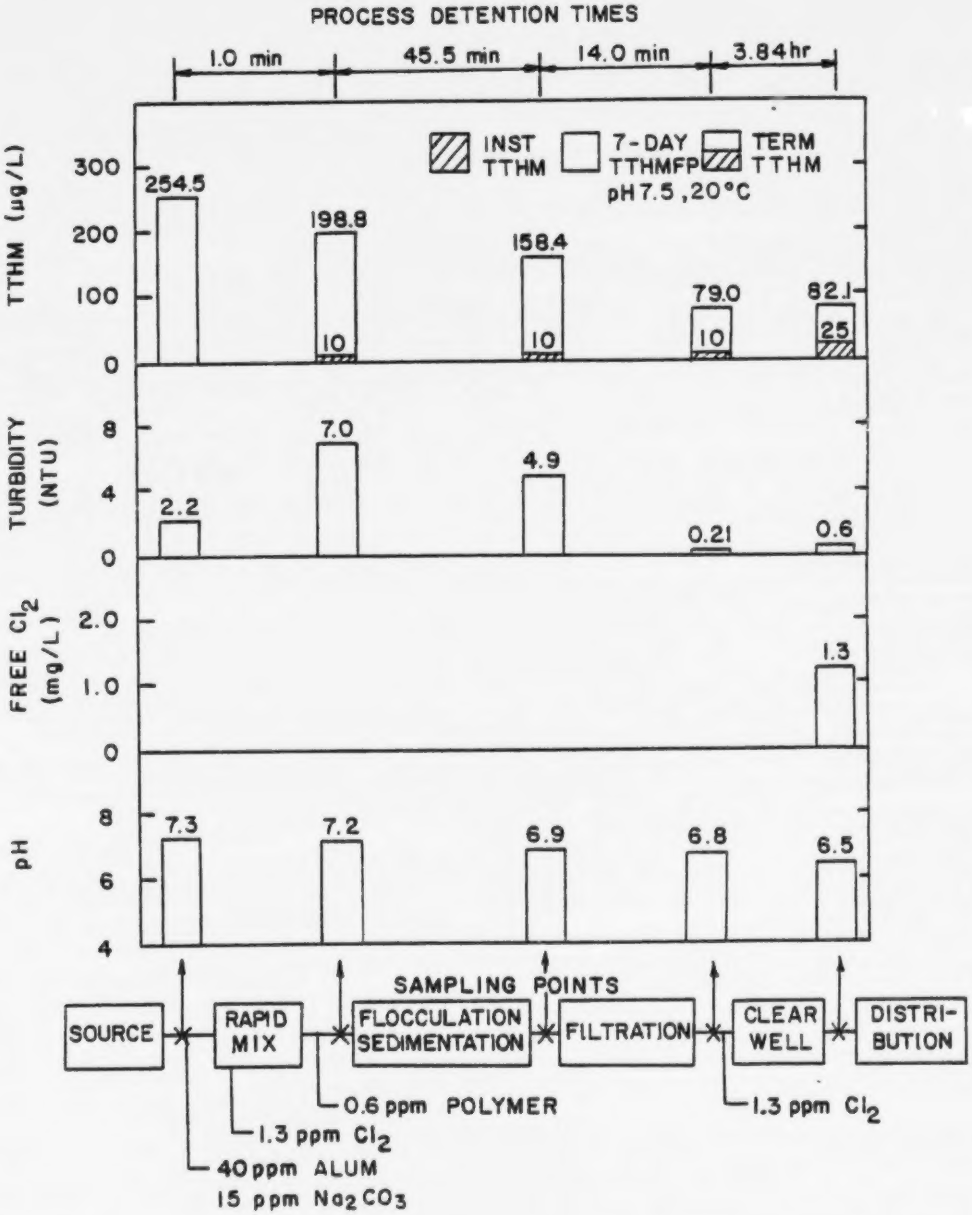


Figure 15. Monitoring results for the Canton water plant on 1/26/81 (Flow 11.4 ML/d (3 MGD), 1-2.5°C), part B.

16 and 17. These conditions contrast greatly with the raw water quality conditons discussed above for the low TOC and low TTHMFP monitoring case.

The flow rate was 11.4 ML/d (3 MGD) so the process detention times are identical to the earlier case. An alum dose of 50 mg/L was used but without the addition of soda ash; consequently, pH values after cogulation were low - pH 5-5.7 through the plant (Figure 17). A prechlorination dose of 2.5 mg/L was used, but no free chlorine residual was measured ahead of the clearwell. A postchlorination dose of 1.5 mg/L was used.

Figure 16 shows that good removals through the plant were achieved. In contrast to the previous case, however, sedimentation is more efficient. Settled removals for UV absorbance, NPTOC, and Term TTHM were 66%, 47%, and 51%, respectively. After filtration, cumulative (settled plus filtered) removals for UV, NPTOC, and Term TTHM were 86%, 70%, and 73%, respectively.

Inst TTHMs through the plant were extremely low - clearwell effluent of 45 μg/L - considering the high concentration of THM precursor in the raw water and the remaining TTHMFP of the finished water. Two reasons are given for the low Inst TTHMs - the low pH conditions through the plant and the chlorination practice. Figure 17 shows that alum addition without soda ash lowered the pH from 7.0 to 5.0 (settled effluent). The pH leaving the plant was 5.7. In spite of the high organic concentration of the raw water, a relatively low prechlorination dose of 2.5 mg/L was used with no free chlorine residual measured ahead of the clearwell.

No prechlorination--The last case presented is for 3/24/82 when no prechlorination was being practiced. The results are presented in Figures 18 and 19. This case was during spring runoff conditions so NPTOC (5.6 mg/L) and TTHMFP (302 μg/L) concentrations for the Grasse River are relatively low. Chemical treatment consisted of 12 mg/L soda ash, 40 mg/L alum, and 0.8 mg/L of polymer. The postchlorination dose was 4 mg/L.

Good removals of organic matter and THM precursors were achieved, but with the low water temperature (0.5-2°C) most of the removals occurred on the filters (Figure 18). No Inst TTHMs were detected except for the clearwell effluent (3.5 μg/L). Figure 19 shows low pH conditions (6.2-6.3) through the plant. The pH conditions combined with the low water temperature and no prechlorination explains the low Inst TTHM concentration of 3.5 μg/L for the finished water.

Performance Summary--

All of the performance data in terms of cumulative percent removals for total UV, NPTOC, and Term TTHM through sedimentation and filtration are presented in Table 16. The cumulative settled removals include the combined effect of coagulation-flocculation-sedimentation, while cumulative filtered removals add filtration. Settled and filtered turbidities are also presented in the table along with the finished water (clearwell effluent) Inst TTHM concentrations. The last column labeled comments contains pertinent information about chlorination and pH conditions.

Filtered removals are used to determine overall plant perforamnce. The

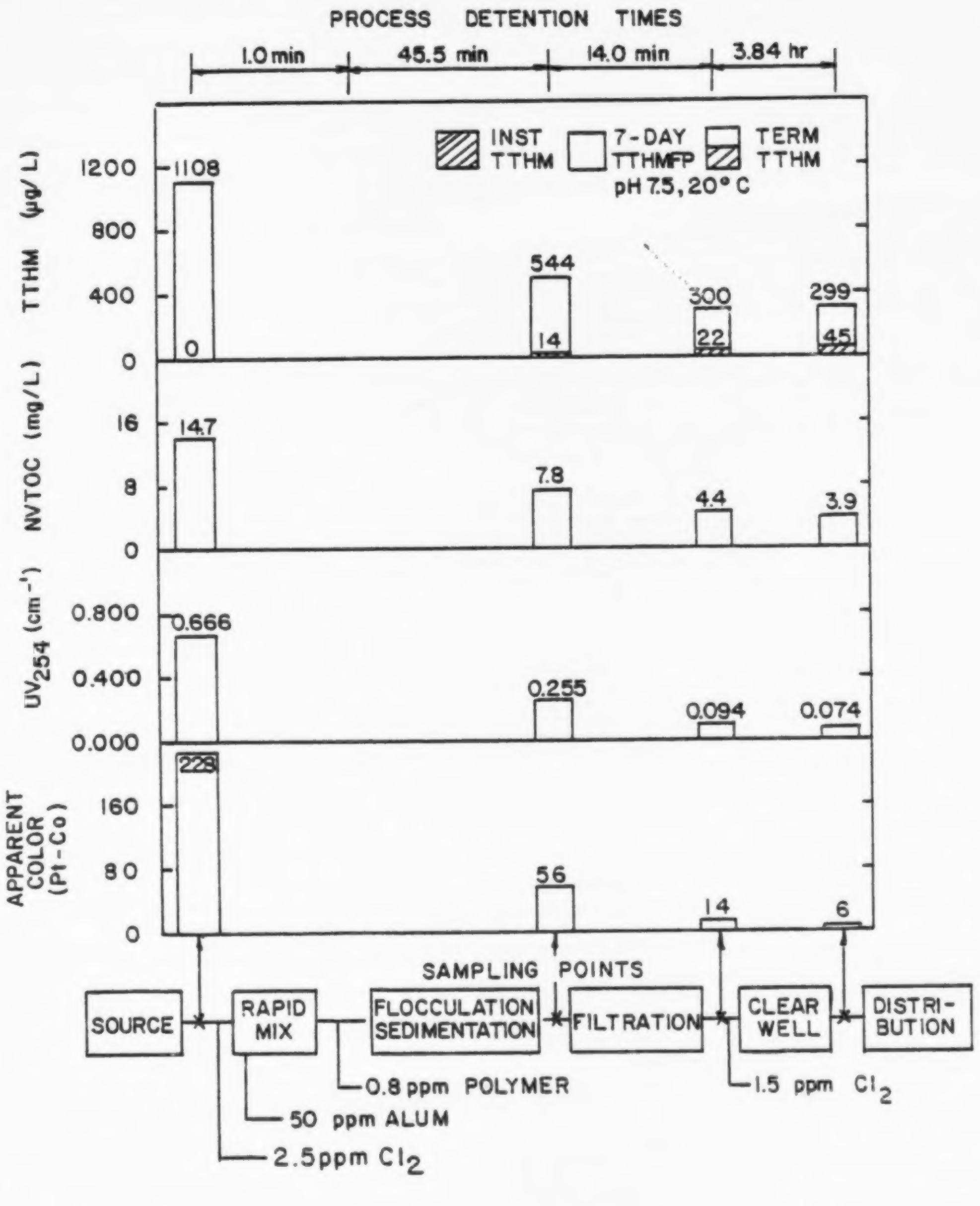


Figure 16. Monitoring results for the Canton water plant on 8/19/81 (Flow 11.4 ML/d (3 MGD), 18-19.5 °C), part A.

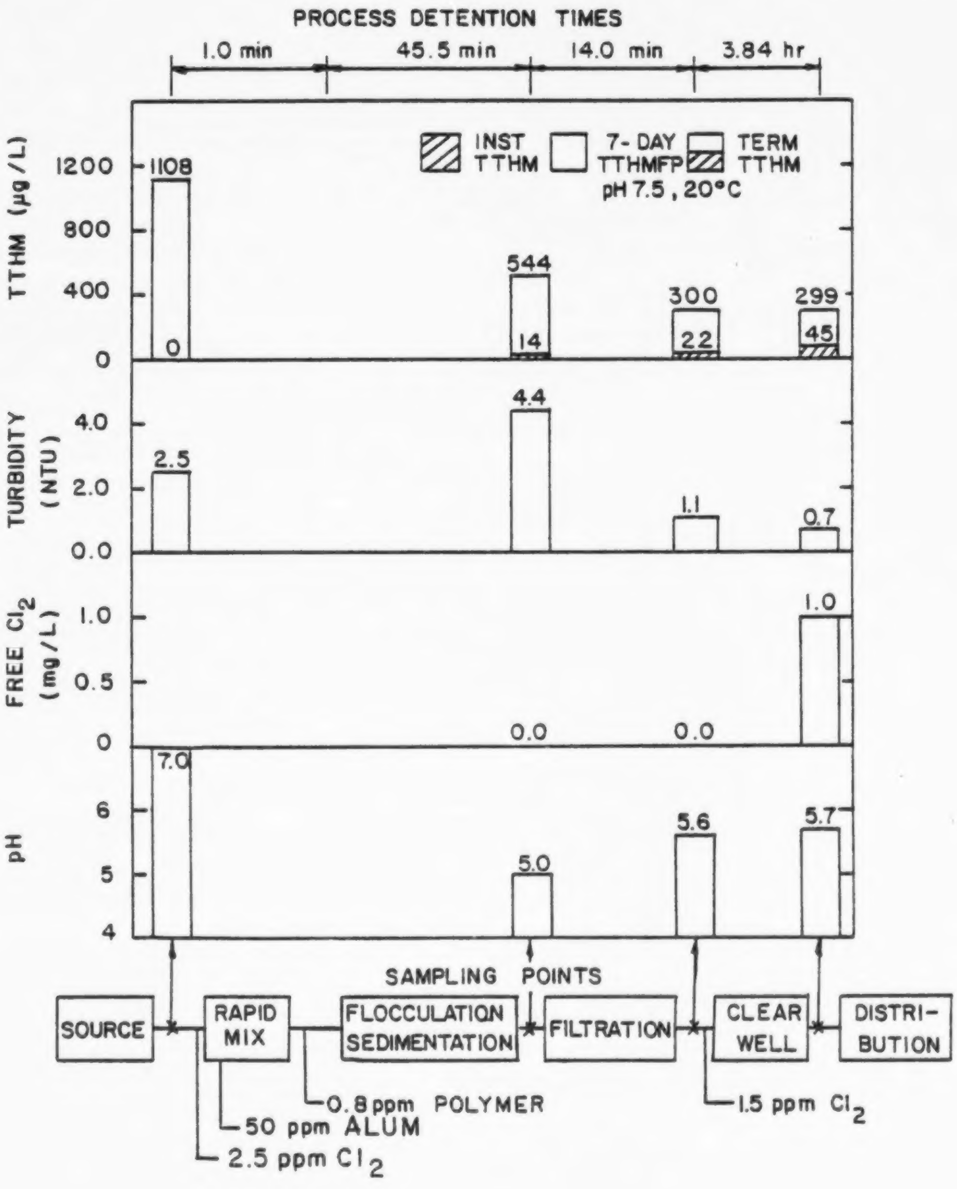


Figure 17. Monitoring results for the Canton water plant on 8/19/81 (Flow 11.4 ML/d (3 MGD), 18-19.5 °C), part B.

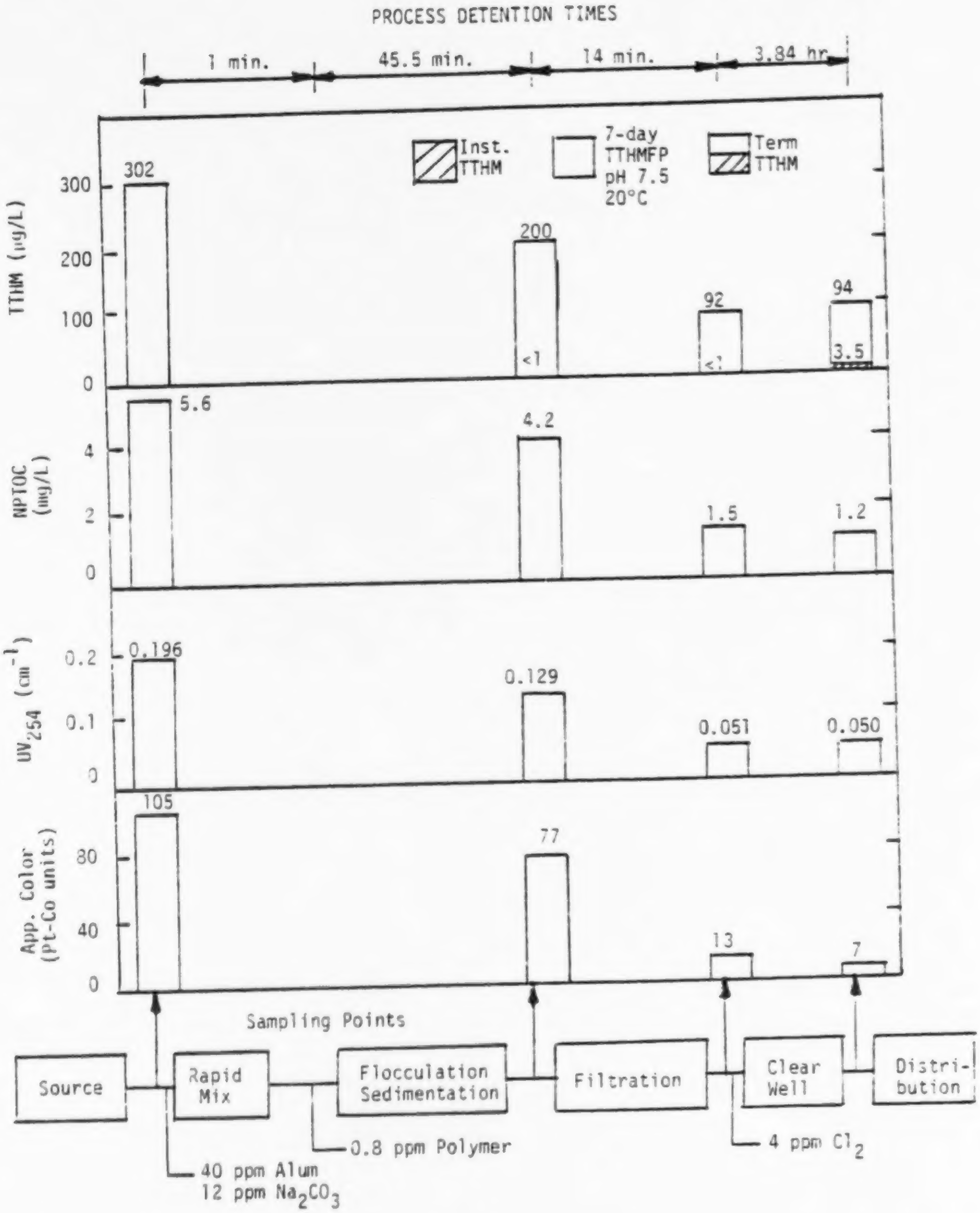


Figure 18. Monitoring results for the Canton water plant on 3/24/82 (Flow 11.4 ML/d (3 MGD), Temp. 0.5-2°C), part A.

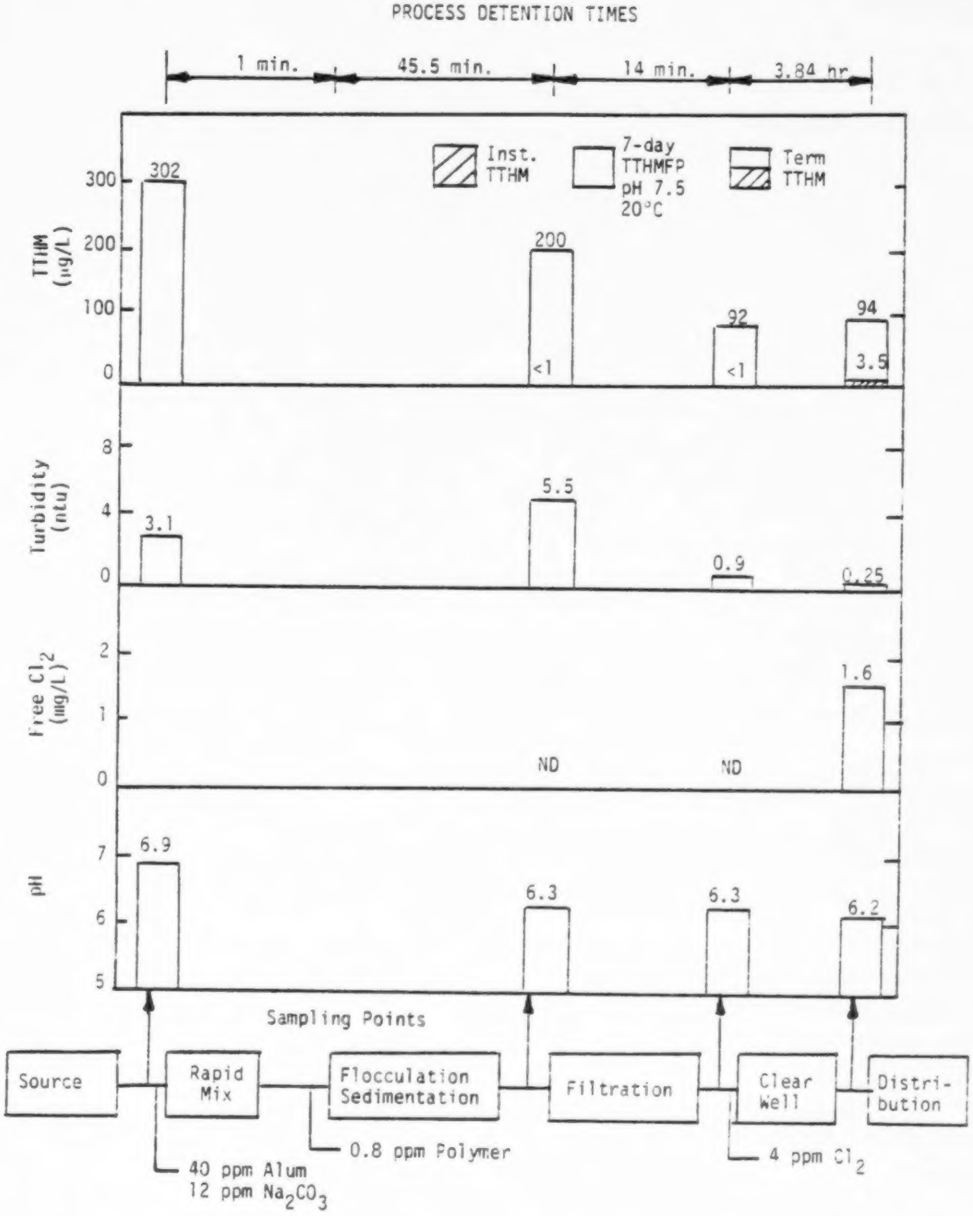


Figure 19. Monitoring results for the Canton water plant on 3/24/82 (Flow 11.4 ML/d (3 MGD), Temp. 0.5-2°C), part B.

TABLE 16. PERFORMANCE DATA FOR THE CANTON WATER FILTRATION PLANT

Date	Raw Water Temperature (°C)	Cumulative Percent Removal - Settled			Settled Turbidity (ntu)	Filtered Turbidity (ntu)	Cumulative Percent Removal -- Filtered			Finished Inst TTHM (μg/L)	Comments
		Total UV	NPTOC	Term TTHM			Total UV	NPTOC	Term TTHM		
4/10/80	0.5	63	20	46	2.1	0.13	86	56	71	10	(1)1.2 mg/L, (2)1.0 mg/L
4/7/80	5	45	0	26	4.0	0.64	73	64	61	51	(1)1.0 mg/L,(2)2.0 mg/L
5/29/80	18	63	*	49	1.7	0.22	68	*	69	39	(1)1.0 mg/L,(2)1.2 mg/L pH 5.9-6.1 thru plant
8/5/80	23	82	54	60	1.9	0.30	84	69	*	127	(1)2.0 mg/L, (2)2.0 mg/L
10/13/80	11	59	17	39	6.2	0.12	74	73	75	47	(1)1.0 mg/L,(2)1.8 mg/L pH 6.1 thru plant
12/12/80	5	67	43	52	3.5	0.10	87	67	79	31	(1)1.2 mg/L,(2)1.2 mg/L
1/26/81	1	14	7	38	4.9	0.21	67	60	69	25	(1)1.3 mg/L, (2)1.3 mg/L
3/12/81	2	37	32	42	4.2	0.18	83	66	71	33	(1)1.5 mg/L, (2)1.5 mg/L
5/7/81	12	63	57	57	2.2	0.44	83	80	71	20	(1)1.5 mg/L,(2)1.5 mg/L pH 6.5 thru plant
6/18/81	19	75	49	61	2.7	0.50	84	71	78	96	(1) 2.0 mg/L,(2) 2.0 mg/L pH 6.2-6.5 thru plant
8/19/81	19.5	66	47	51	4.4	1.1	86	70	73	45	(1)2.5 mg/L, (2) 1.5 mg/L pH 5.0-5.7 thru plant
10/15/81	9	64	31	53	7.0	0.31	85	77	80	1	(1)None, (2) 2.0 mg/L pH 5.8-6.1 thru plant
12/10/81	2.5	32	38	43	3.4	0.23	83	79	70	19	(1)None, (2) 2.0 mg/L
1/15/82	0.5	52	25	55	4.9	0.20	81	58	74	20	(1)None, (2) 2.2 mg/L
2/18/82	2	51	34	42	3.7	1.0	79	*	68	18	(1) 2.0 mg/L, (2) None
3/24/82	0.5	34	25	34	5.5	0.9	74	73	70	4	(1) None, (2) 4.0 mg/L pH 6.2-6.3 thru plant
Average	8	54	32	47	3.9	0.41	80	69	72	37	
Std. Dev.	8	18	17	10	1.6	0.33	7	8	5	33	

*Not Available (1) Prechlorination dosage; (2) Postchlorination dosage data show that the plant is effective with average removals of 80%, 69%, and 72% for UV absorbance, NPTOC, and Term TTHM, respectively. The low standard deviations indicate rather constant overall plant performance. The data for settled removals indicate greater variability and, on the average, only 32% of the TOC and 47% of the Term TTHM is removed prior to filtration.

The three illustrative monitorings previously presented indicated that sedimentation performance is temperature dependent - i.e., a much larger portion of the total removals was accomplished by sedimentation under warm water conditions as compared to cold water conditions. In the next two subsections, the effects of temperature on plant performance and THM formation are examined.

Effect of temperature on performance--If one examines the settled turbidity data in Table 16, there is no apparent effect of temperature on sedimentation with regard to the turbidity going to the filters. However, the turbidity alone is not sufficient in evaluating removal of organic matter. To examine temperature effects, the monitoring data were divided into two categories based on raw water temperature: 0.5 to 5°C and 9 to 23°C. The lower temperature range includes 9 monitorings and represents treatment performance from December into early April (winter and spring snowmelt periods). The higher temperature range includes 7 monitorings and represents performance for late spring, summer, and fall.

Average cumulative percent removals are presented in Table 17. The data show that removals by sedimentation were much better under warm water conditions. For example under cold water conditions, average removals for TOC and Term TTHM were 25% and 42% by sedimentation compared to 43% and 53% for these parameters under warm conditions. It is recalled that NPTOC, Term TTHM, and total UV data are for samples that were not filtered in the laboratory (measure of soluble and suspended material). Therefore, the data show the ability of the plant to coagulate organic matter and remove it by sedimentation. The results indicate that the material is coagulated and floc is formed, since the material is removed by the filters. However due to the cold water conditions which increase fluid viscosity (fluid density effects would be minor), settling of the floc is poor. These results support the conclusions of Camp et al. (1940) who evaluated the effects of cold water temperatures on water plant performance. Camp et al. attributed poor water plant performance in the winter, not to floc formation (coagulation) but to poor settling.

Another significant conclusion is that overall plant performance (filter effluent) is independent of temperature. That is, there is little difference in the cumulative removals for the filtered data indicating that during the winter the filters do most of the work while under warm water conditions, removal by sedimentation is better and the filters do less work on a percentage basis.

THM formation in the Canton water plant--THM formation through the treatment plant is dependent on precursor concentration, chlorination practice, pH, and temperature. Some discussion of these factors was presented with the illustrative monitorings. Here discussion is first

TABLE 17. EFFECTS OF WATER TEMPERATURE ON PERFORMANCE OF THE CANTON WATER FILTRATION PLANT (n=16)

	Temp 0.5-5°C (n=9)		Temp 9-23°C (n=7)	
	% Removed Settled*	% Removed Filtered+	% Removed Settled	% Removed Filtered+
Tot UV	44 (17)	79 (7)	67 (8)	81 (7)
NPTOC	25 (14)	65‡ (8)	43§ (15)	73§ (4)
Term TTHM	42 (9)	70 (5)	53 (8)	74§ (4)

( ) Standard deviation

* Cumulative removal: coagulation-flocculation-sedimentation

+ Cumulative removal: coagulation-flocculation-sedimentation-filtration

‡ n=8

§ n=6

TABLE 18. EFFECTS OF TEMPERATURE AND PRECHLORINATON ON FINISHED WATER INST TTHMs AT CANTON, N.Y.

Case	n	Avg. Finished Inst TTHM (μg/L)
All Data	16	37 (33)
Temp.		
0.5-5°C	9	23 (14)
9-23°C	7	54 (44)
Prechlorination		
None (0.5-9°C Temp)	4	11 (10)
Pre-Cl$_2$ (0.5-11°C Temp)	7	31 (15)

( ) Standard deviation

devoted to the effects of temperature and prechlorination, followed by a general summary discussion.

The finished water Inst TTHM data (water being pumped form the clearwell to the distribution system) are used in this discussion. As shown at the bottom of Table 16 and presented again in Table 18, the average Inst TTHM for the 16 monitorings is 37 μg/L with, as expected, a high standard deviation due to the variables mentioned above which influence THM formation through the water plant. Under raw water temperature conditions of 0.5 to 5°C, the average value falls to 23 μg/L, and under warmer water temperatures (9 to 23°C) the value rises to 54 μg/L. Only twice was the finished Inst TTHM near or above 100 μg/L - on 8/5/80 and 6/18/81. This is expected considering the higher water temperatures, use of prechlorination, and high precursor levels during the summer. The finished water Inst TTHM on 8/19/81 was low (45 μg/L). This was previously discussed under the illustrative case of high TOC-high TTHMFP. The low value was explained by the low pH conditions and chlorination practice.

Prechlorination was discontinued by the plant on 4 monitoring dates as noted in Table 16. This evaluation occurred in the last year of the project on dates when the water temperature was 0.5 to 9°C. To compare on a similar water temperature basis when prechlorination was practiced, 7 monitorings were picked with water temperatures of 0.5 to 11°C. The results at the bottom of Table 18 show a significantly lower Inst TTHM concentration without prechlorination - 11 μg/L vs. 31 μg/L.

In summary, the Canton water plant has low finished water Inst TTHMs considering the high precursor concentraitons in the raw water. This is due to the low water temperatures, the chlorination practice, the pH of treatment, and the short hydraulic detention time for the treatment plant. The effect of prechlorination was discussed above. However even when prechlorination is used, doses are typically 1 to 2 mg/L. Total chlorine dosages (pre- and post-chlorination) are normally 2 to 4 mg/L. These low doses of chlorine prevent high THM formation in the plant. The detention times for flocculation-sedimentation and filtration are 45.5 min and 14 min for the plant's typical flow of 11.4 ML/d (3 MGD). Thus, THM precursors can be removed in the plant before large amounts of precursors have been converted into THMs. The relatively low pH conditions during treatment also limit THM formation. Normally the plant is operated between pH 6 to 7, and on some occasions the pH is as low as 5 in the front end of the plant.

Distribution system trihalomethanes--The EPA maximum contaminant level (MCL) for TTHMs is 0.10 mg/L. This is for Inst TTHMs in the distribution system and is based on a running yearly average for quarterly sampling of 4 samples from representative points in the distribution system. One sample from the far end of the distribution system and the other sampling points from representative locations with respect to population distribution. To evaluate Inst TTHMs in the Canton water system, three sampling points were used in the data analysis - Point 5, the clearwell effluent; Point 6, the Canton Bakery; and Point 7, the Canton municipal wastewater treatment plant at the far end of the water distribution system. These sampling locations were described at the beginning of Section 6.

An important feature of the Canton system is that it has two water sources: The Grasse River which is treated at the Canton Water Filtration Plant and a groundwater. The groundwater receives no treatment other than chlorination prior to entering the distribution system. The groundwater is extremely low in TOC and THM precursors. Our laboratory has measured the TOC at 0.3 mg/L and the 5-day TTHMFP (pH 7.5, 20°C) at 28 μg/L. Mixing of the groundwater with the treated Grasse River water dilutes the Inst TTHMs in the distribution system. The fraction of groundwater in the distribution system is highly variable on both a daily and seasonal basis and thus cannot be quantitatively accounted for. Canton is a college town with one 4-yr university and a 2-yr college. Highest water demands are in the late summer (September) and early fall after the students return to school. Lowest water demands are in the late spring and summer. The river is used to a greater degree when the demands are high (colleges in session). Most of the time this corresponds to lower THM precursor levels. Another complication in interpreting distribution system THM data is the possible loss of THMs from water to the atmosphere in distribution storage reservoirs.

The data are presented in Table 19. Temperature and free chlorine residuals are given, if known. The table also contains data for a 7-day stored sample. For this, a sample of finished water (clearwell effluent) was collected and held for 7 days at 20°C. It was then quenched with sodium sulfite and the THMs measured. It is indicative of the maximum TTHM concentration that could be formed at 20°C in the distribution system if no additional chlorine were added. As expected Inst TTHM concentrations in the distribution system are below 100 μg/L. The only exception was for 8/5/80.

The three distribution system samples (Points 5, 6, 7) have been averaged for each date as would be done with respect to EPA monitoring regulations. The results are presented in Table 20. In no case is 100 μg/L exceeded. The low concentrations, below 30 μg/L, for the last 5 monitorings is attributable, in part, to water temperature and prechlorination practice, but is also influenced by the groundwater source.

ONEIDA WATER TREATMENT PLANT EVALUATION

Plant Description

The Oneida Water Treatment Plant is a conventional plant with a rated process capacity of 15.1 ML/day (4 MGD). It was monitored periodically during this study to evaluate its performance for removal of organic matter and THM precursors, and to compare with direct filtration performance. The plant is located approximately 1/2 mile south of the Glenmore Reservoir, and approximately 20 miles north of the City of Oneida, as shown in Figure 20. The plant was completed in early 1980, and first put into operation in April of that year. Until that time, only chlorination and lime addition for corrosion control were practiced. This was done at the old treatment plant, which is located approximately halfway between Glenmore Reservoir and the new treatment plant.

TABLE 19. CANTON DISTRIBUTION SYSTEM TRIHALOMETHANE DATA

Date	Location	Temp °C	Free Cl_2 mg/L	Inst. THM µg/L
4/7/80	Point 5	6	0.4	51.0
	Bakery*	6	0.3	49.3
	MWWTP+	6	0.4	42.5
	7 day stor.	20	NA	93.5
5/29/80	Point 5	18	0.9	39.0
	Bakery	12	0.5	36.7
	MWWTP	10	0.5	40.3
	7 day stor.	20	NA	69.9
8/5/80	Point 5	22	0.2	126.8
	Bakery	19	0.3	33.0
	MWWTP	18	0.4	100.0
	7 day stor.	20	NA	128.9
10/13/80	Point 5	12	0.3	47.4
	Bakery	13	1.1	53.4
	MWWTP	13	0.7	47.6
	7 day stor.	20	NA	63.1
12/12/80	Point 5	5	0.6	31.0
	Bakery	10	0.5	37.8
	MWWTP	10	0.5	42.6
	7 day stor.	20	NA	61.2
1/26/81	Point 5	3	1.7	24.6
	Bakery	4	1.0	15.8
	MWWTP	4	1.0	22.3
	7 day stor.	20	NA	49.3
3/12/81	Point 5	3	1.5	32.9
	Bakery	8	1.1	26.7
	MWWTP	8	0.8	33.1
	7 day stor.	20	NA	72.0
5/7/81	Point 5	14	1.5	20.0
	Bakery	11	0.8	37.9
	MWWTP	10	1.0	37.8
	7 day stor.	20	NA	59.7
6/18/81	Point 5	15	1.2	95.5
	Bakery	NA	NA	16.2
	MWWTP	NA	NA	17.4
	7 day stor.	20	NA	105.6

(continued)

TABLE 19. (continued)

Date	Location	Temp °C	Free Cl_2 mg/L	Inst. THM μg/L
10/15/81	Point 5	11	1.6	1.0
	Bakery	NA	NA	35.4
	MWWTP	NA	NA	33.4
	7 day stor.	20	NA	37.5
12/10/81	Point 5	2	1.3	18.7
	Bakery	NA	NA	32.6
	MWWTP	NA	NA	32.9
	7 day stor.	20	NA	100.3
1/15/82	Point 5	2	1.6	20.4
	Bakery	NA	NA	23.4
	MWWTP	NA	NA	24.1
	7 day stor.	20	NA	68.4
2/18/82	Point 5	4	0.8	18.0
	Bakery	NA	NA	18.2
	MWWTP	NA	NA	15.4
	7 day stor.	20	NA	55.7
3/24/82	Point 5	2	1.6	3.5
	Bakery	5	0.7	25.6
	MWWTP	5	0.8	25.0
	7 day stor.	20	NA	36.6

* Bakery located on Route 11 (Point 6)

+ Canton Municipal Wastewater Treatment Plant (MWWTP) (Point 7)

NA Not Available

TABLE 20. AVERAGE DISTRIBUTION SYSTEM INST TTHMs FOR CANTON, N.Y. (Points 5, 6, and 7)

Date	Average Inst TTHM (μg/L)	Comments
4/7/80	48	
5/29/80	39	pH 5.9-6.1 thru plant
8/5/80	87	
10/13/80	49	pH 6.1 thru plant
12/12/80	37	
1/26/81	21	
3/12/81	31	
5/7/81	32	pH 6.5 thru plant
6/18/81	43	pH 6.2-6.5 thru plant
10/15/81	23	No prechlorination, pH 5.8-6.1 thru plant
12/10/81	28	No prechlorination
1/15/82	23	No prechlorination
2/18/82	17	
3/24/82	18	No prechlorination, pH 6.2-6.3 thru plant
All Dates	35	
n=14	(18) standard deviation	

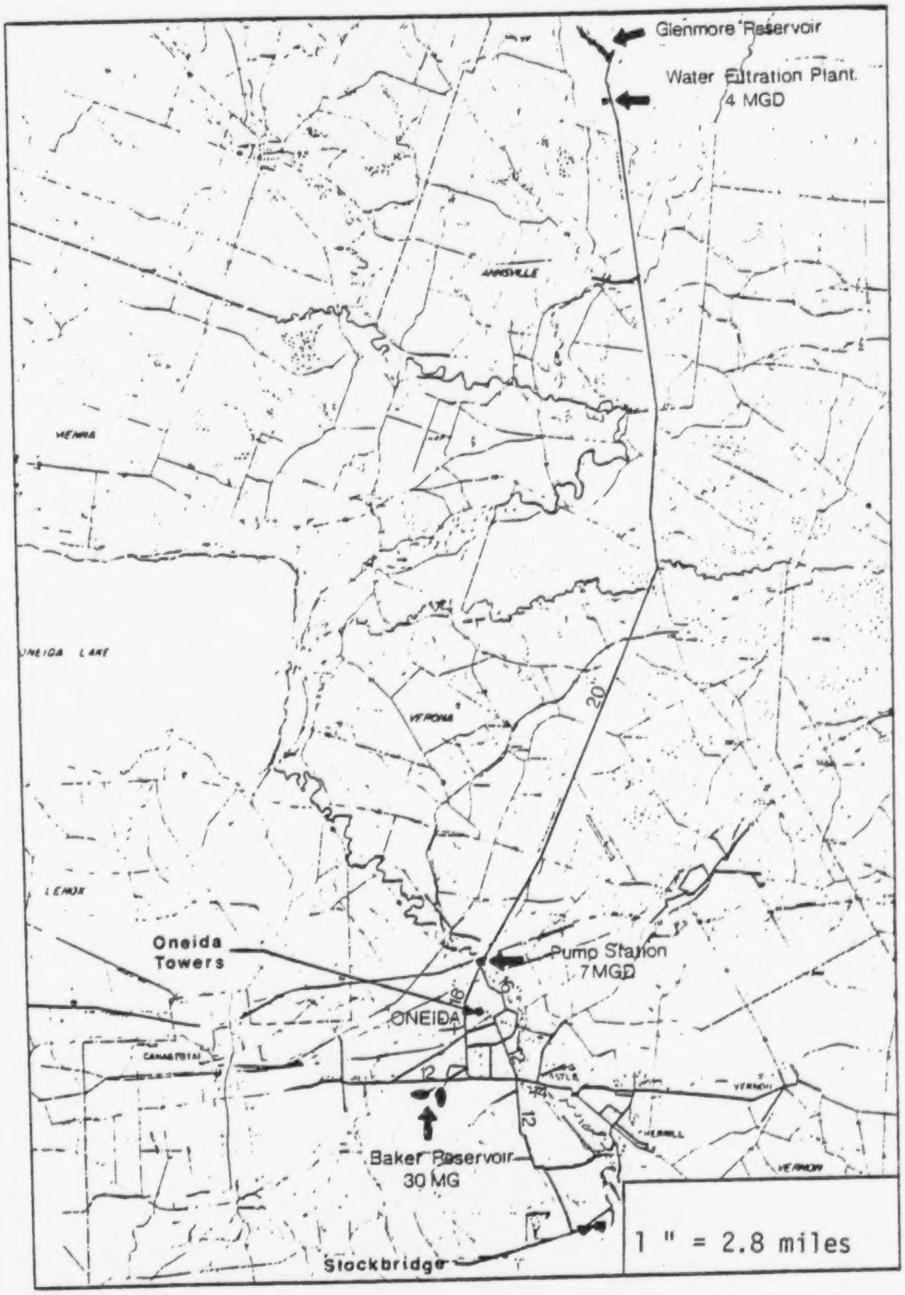

Glenmore Reservoir
Water Filtration Plant 4 MGD
ANNSVILLE
VIENNA
ONEIDA LAKE
VERONA
20
LENOX
Oneida Towers
Pump Station 7MGD
46
ONEIDA
CANASTOTA
12
365
VERNON
SHERRILL
Baker Reservoir 30 MG
Stockbridge
1 " = 2.8 miles

Figure 20. City of Oneida water system

A schematic of the treatment plant is presented in Figure 21. Alum is added in the rapid mix basin to serve as the primary coagulant. When the plant was first started up (April 1980), the New York Department of Health required that predisinfection be practiced. At that time, facilities for prechlorinating in the rapid mix tank were not yet complete, so chlorine was added at the old treatment plant. Later that year (June), the Health Department permitted discontinuation of prechlorination. After prechlorination was terminated, it was discovered that high levels of reduced iron and possibly, manganese were present in the Glenmore Reservoir. At that time only chlorine was available to oxidize these metals, and it was fed to the rapid mix tank until September 1980. Then, facilities for using chlorine dioxide became available, and it was used to oxidize reduced metals until October 1980. At about that time, the reservoir usually experiences fall overturn, and reduced metals are no longer a problem. By the spring of 1981, facilities for using potassium permanganate ($KMnO_4$) for oxidation of metals were installed, and it was used exclusively, when needed (usually April-October), for the remainder of this study.

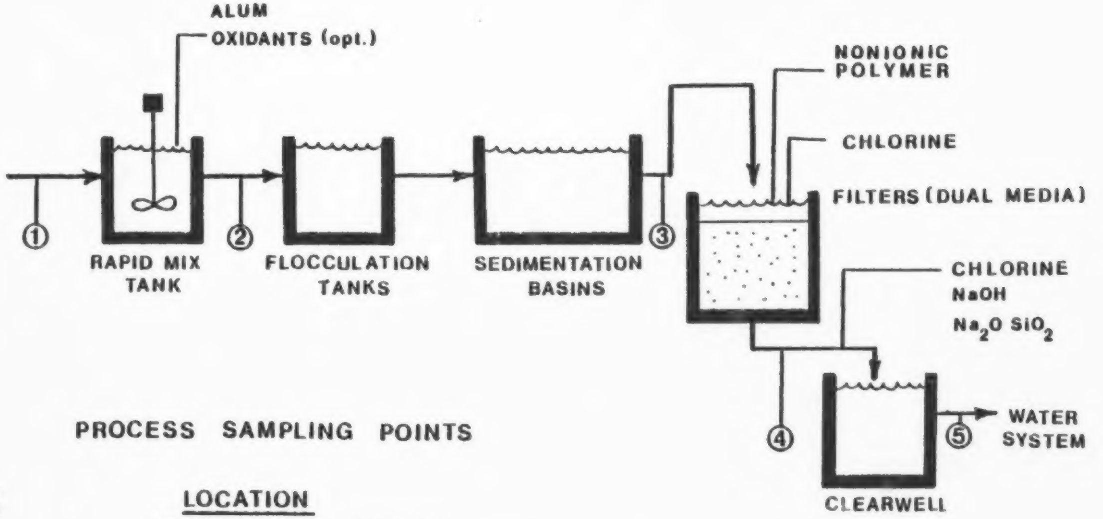
Rapid mixing is followed by flocculation and sedimentation, and then by filtration with dual media filters. Here unlike Canton, conventional sedimentation basins are used. A small dosage of nonionic polymer (Calgon L650E, Calgon Corp.) is used as a filter aid. Chlorine is applied to the top of the filters. Postchlorination follows filtration, along with the addition of NaOH and sodium silicate for corrosion control. The treated water is stored in the clearwell prior to distribution.

Samples were collected at five points in the treatment train. Point 1 is the raw water inlet to the plant, prior to the addition of any chemicals. Point 2 is the rapid mix effluent. This point was eliminated after the May 20, 1981 monitoring. Point 3 is the sedimentation basin effluent. Point 4 is the filter effluent, and Point 5 is the clearwell effluent.

Samples for Inst TTHMs were also collected at two locations in the distribution system. These two points, Point 6 at Oneida Towers and Point 7 at the Stockbridge Pumping Station, are indicated on Figure 20. Oneida Towers was chosen because it is approximately in the middle of the distribution system, and precedes Baker Reservoir. This is an open-air reservoir, so THMs may escape to the atmosphere from the water. Water leaving Baker Reservoir is rechlorinated as it reenters the distribution system. Point 7 at Stockbridge, which is at the far end of the distribution system, would normally receive water which has passed through Baker Reservoir and has been rechlorinated.

Oneida Performance

Monitoring results are presented and discussed in this section. A total of 16 monitorings were conducted between April 1980 and May 1982. Raw water data for the monitoring dates were previously presented in Table 14. Emphasis here is on the removal of organic matter and THM precursors with some consideration of the effect of treatment practice on THM formation. The reader is reminded that treatment practice varied significantly when the


ALUM
OXIDANTS (opt.)
①
RAPID MIX TANK
②
FLOCCULATION TANKS
SEDIMENTATION BASINS
③
NONIONIC POLYMER
CHLORINE
FILTERS (DUAL MEDIA)
CHLORINE
NaOH
Na2O SiO2
④
CLEARWELL
⑤
WATER SYSTEM

PROCESS SAMPLING POINTS

SITE	LOCATION
1	RAW WATER INTAKE
2	INFLUENT TO FLOCCULATION TANKS
3	SETTLED WATER
4	FILTERED WATER
5	FINISHED WATER TO DISTRIBUTION SYSTEM

Figure 21. Process schematic of the Oneida Water Treatment Plant.

plant was first put into operation, particularly with regard to chlorination practice.

Illustrations of Plant Performance--

Low TOC and low TTHMFP--The results of the 3/6/82 monitoring are presented graphically in Figures 22 and 23. This monitoring date was chosen for presentation because it represents the lowest levels of TTHMFP (152 µg/L) and NPTOC (2.0 mg/L) observed for the raw water. The flow rate on this date was 10.6 ML/d (2.8 MGD). An alum dosage of 16 mg/L in the rapid mix tank was used for coagulation. The mean detention time in the rapid mix tank at this flow rate was 2.4 minutes as indicated at the top of the figures. Following rapid mixing, the water flows to the flocculators and sedimentation basins which have a combined detention time of 5.0 hours. Chlorine (0.9 mg/L) was applied on the top of the filters along with 0.09 mg/L of Calgon L650E, a high molecular weight nonionic polymer. The mean detention time through the filters was 56 minutes. Postchlorination consisted of 2.4 mg/L of chlorine before the clearwell. The mean detention time in the clearwell was 4.3 hours. From here finished water flows to the distribution system. Sodium silicate and sodium hydroxide were added for corrosion control.

Samples of raw water, sedimentation effluent, filter effluent, and clearwell effluent were collected and analyzed. Removals of organic parameters were good (see Figure 22), but note that most of the removal took place in the filters - e.g., 19% of the TOC is removed by coagulation-flocculation-sedimentation, but an additional 50% is removed by filtration. A low Inst TTHM concentration of 10 µg/L leaving the plant may be attributed to the cold water temperature (3-7°C through plant), low levels of THM precursors in the raw water, chlorination practice, and efficient precursor removal.

High TOC and high TTHMFP--In contrast to the raw water quality conditions above, Figures 24 and 25 present results for 7/22/81. The raw water TTHMFP and NPTOC values of 597 µg/L and 10.6 mg/L, respectively, represent the highest observed for Oneida. The flow rate on this date was 10.4 ML/d (2.75 MGD), so detention times are similar to the 3/6/82 monitoring previously discussed. A much higher alum dosage of 44 mg/L was used for coagulation. Potassium permanganate (0.4 mg/L) was used to oxidize reduced metals which occur in the reservoir during the summer months. Other chemical dosages are similar to the 3/6/82 monitoring except a much higher postchlorination dosage of 6.5 mg/L was used.

Again, removals were very good (see Figure 24), but in this instance a much larger portion of the removal is accomplished by sedimentation. A finished water Inst TTHM level of 60 µg/L was measured, which is relatively low in view of the raw water quality and warm temperature. Part of this is due to the low pH conditions maintained in the plant prior to the clearwell (see Figure 25).

Summary Performance--

All of the performance data in terms of cumulative percent removal for total UV, NPTOC, and Term TTHM through sedimentation and filtration are presented in Table 21. Settled and filtered turbidities are also presented

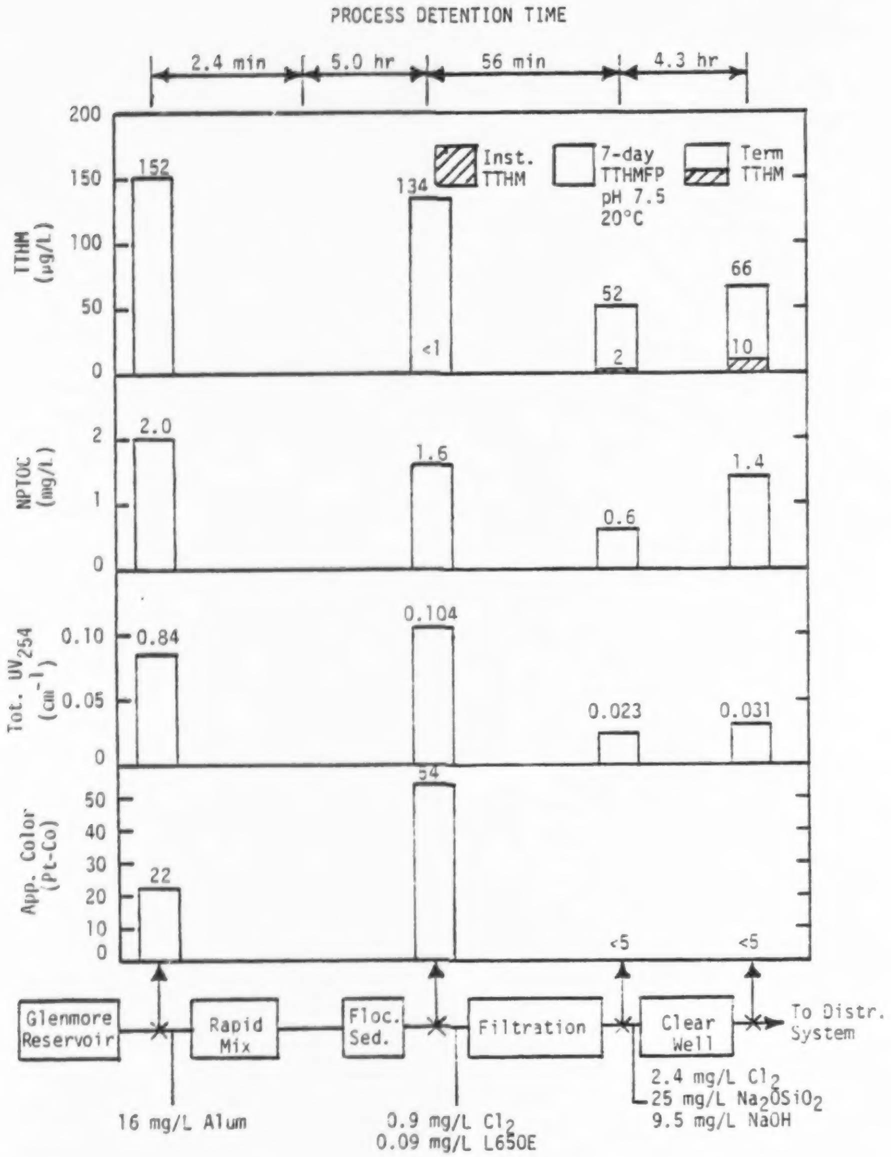


Figure 22. Monitoring results for the Oneida WTP on 3/06/82 (Flow 10.6 ML/d (2.8 MGD), Temp. 3°-7°C), part A.

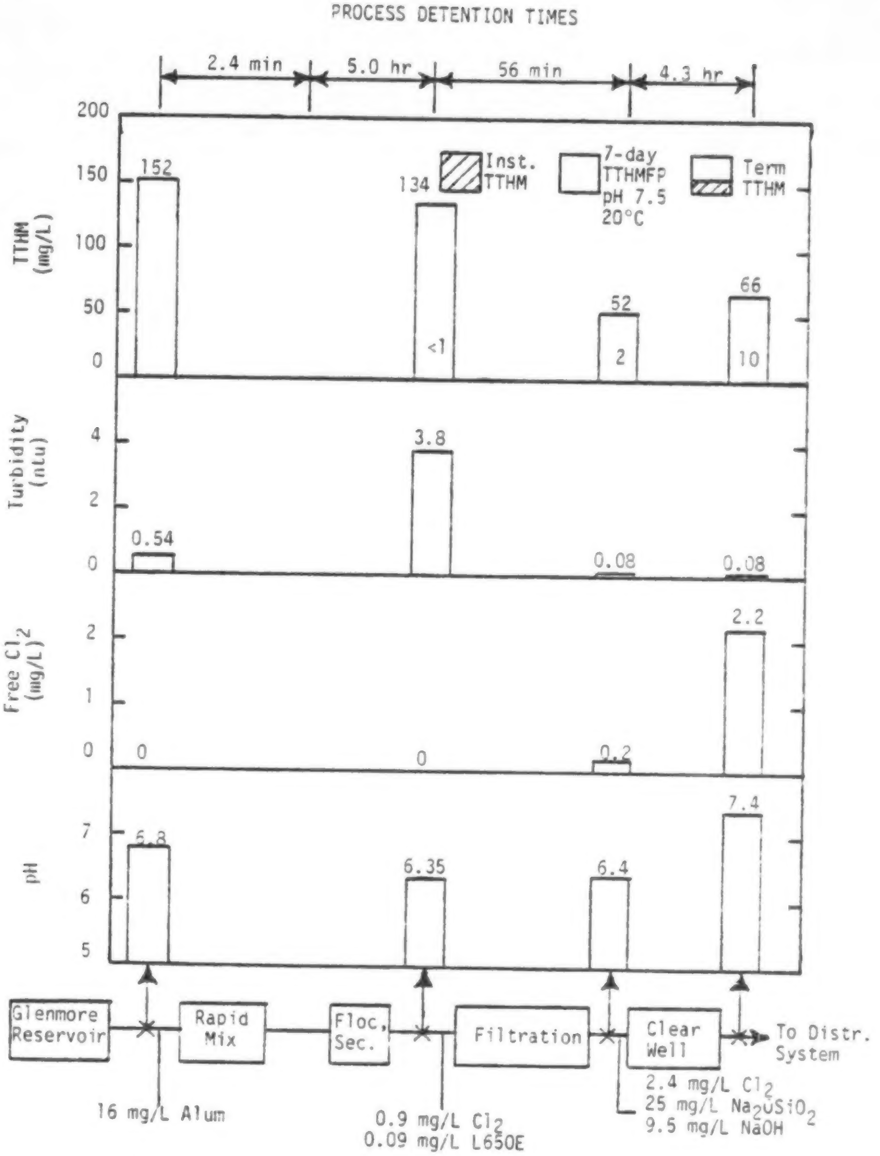


Figure 23. Monitoring results for the Oneida WTP on 3/06/82 (Flow 10.6 ML/d (2.8 MGD), Temp. 3°-7°C), part B.

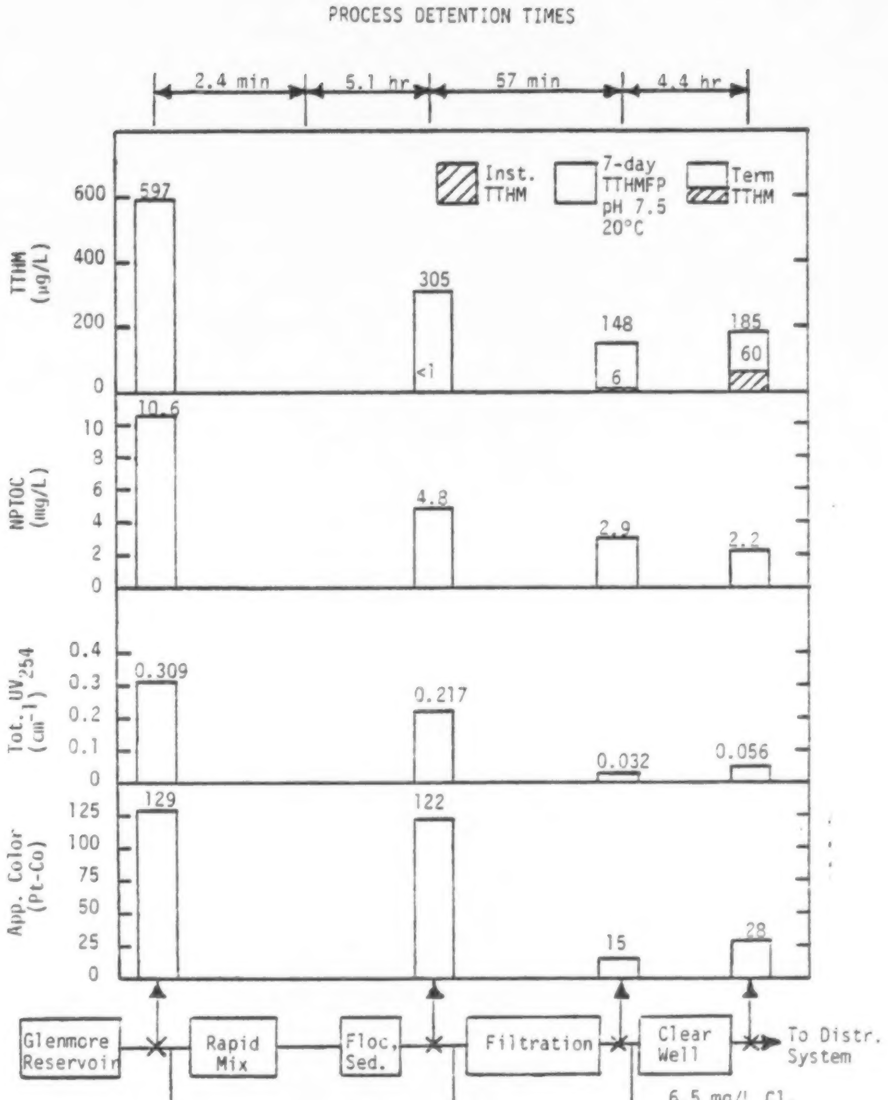


Figure 24. Monitoring results for the Oneida WTP on 7/22/81 (Flow 10.4 ML/d (2.75 MGD), Temp. 20°-23°C), part A.

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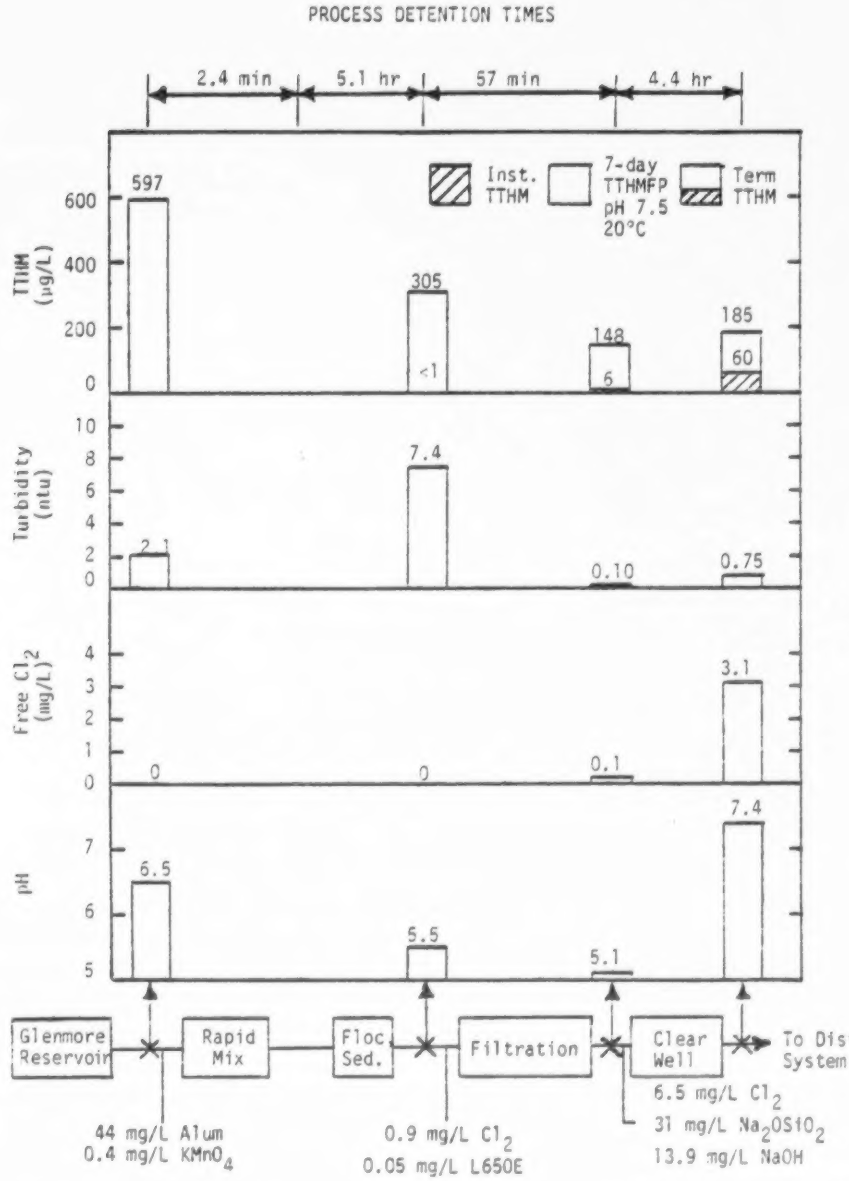

Figure 25. Monitoring results for the Oneida WTP on 7/22/81 (Flow 10.4 ML/d (2.75 MGD), Temp. 20°-23°C), part B.

TABLE 21. PERFORMANCE DATA FOR THE ONEIDA WATER TREATMENT PLANT

Date	Raw Water Temperature (°C)	Cumulative Percent Removal - Settled			Settled Turbidity (NTU)	Filtered Turbidity (NTU)	Cumulative Percent Removal -- Filtered			Finished Inst TTHM (µg/L)	Comments
		Total UV_{254} Abs.	NPTOC	Term TTHM			Total UV_{254} Abs.	NPTOC	Term TTHM		
4/10/80	8	36	*	11	8.5	0.45	76	*	48	148	Pre-chlorinating at old plant, (4.9 mg/L)
6/3/80	14	25	*	14	5.4	0.29	81	*	46	88	No pre-chlorination; 2.9 mg/L Cl_2 top of filters
9/2/80	21	48	-18	*	2.0	0.50	63	47	*	134	Pre-chlorinating in rapid mix tank (4.2 mg/L)
10/14/80	12	36	51	41	2.3	0.26	63	69	48	57	0.7 mg/L ClO_2 in rapid mix
12/19/80	3	10	*	-12	6.5	0.16	84	*	55	43	0.9 mg/L Cl_2 top of filters
2/16/81	3	-11	23	- 4	5.8	0.20	76	42	57	12	0.8 mg/L Cl_2 top of filters
4/20/81	8.5	18	39	41	4.6	0.05	85	71	72	27	0.12 mg/L $KMnO_4$ in rapid mix 0.9 mg/L Cl_2 top of filters
5/20/81	12.5	36	- 4	41	5.0	0.27	82	81	75	37	0.55 mg/L $KMnO_4$ in rapid mix 1.1 mg/L Cl_2 top of filters
6/25/81	19	69	69	71	1.0	0.28	81	59	69	19	0.30 mg/L $KMnO_4$ in rapid mix 0.9 mg/L Cl_2 top of filters
7/22/81	20	30	55	49	7.4	0.10	90	73	75	60	0.4 mg/L $KMnO_4$ in rapid mix 0.9 mg/L Cl_2 top of filters
8/20/81	18	25	52	56	9.3	0.06	83	62	77	30	0.7 mg/L $KMnO_4$ in rapid mix 0.7 mg/L Cl_2 top of filters
10/9/81	10	6	38	25	9.1	0.16	-100**	87	68	36	0.5 mg/L $KMnO_4$ in rapid mix 1.0 mg/L Cl_2 top of filters
11/25/81	6.5	39	48	35	3.9	0.09	82	93	70	20	1.1 mg/L Cl_2 top of filters
1/8/82	4	13	39	24	6.1	0.06	83	78	67	15	1.0 mg/L Cl_2 top of filters
3/6/82	3	24	19	12	3.8	0.08	73	69	66	10	0.9 mg/L Cl_2 top of filters
5/7/82	12	50	24	51	2.0	0.12	80	67	66	23	1.1 mg/L Cl_2 top of filters
Average	11	29	35	31	5.2	0.20	79	69	64	47	
Std. Dev.	11	18	21	21	2.6	0.14	8	14	10	42	

* - Not Available ** - Not used in computing average or standard deviation

Note: Negative removals assumed zero for computation of averages and standard deviation.

in this table, along with the finished water Inst TTHM concentrations. Chlorination and oxidation practice are sumamrized in the comment column. Average values and standard deviations are presented at the bottom of the table. Negative removals were assumed to be zero in computation of these two statistical parameters. The plant was effective in removal of organics and THM precursors, with average total removals of 79 percent, 69 percent, and 64 percent for total UV (254 nm) absorbance, NPTOC, and Term TTHMs, respectively.

Treatment practice varied substantially during the first few months of operation. This was due to a lack of operator familiarity with the plant and varying chlorination and oxidation practice. Consequently, percent removals have also been calculated after elimination of the first four monitorings. These results are presented in Table 22. The average total plant removals are slightly better when this is done, with removals of 82 percent for total UV (254 nm) absorbance, 71 percent for NPTOC, and 68 percent for Term TTHMs. Standard deviations are also lower when the first four monitorings are eliminated, indicating more consistent plant operation.

Effect of temperature on performance--The two illustrative monitorings previously presented seem to indicate that performance of the treatment plant is temperature dependent. A much larger portion of the total removals was accomplished by sedimentation under the warm water conditions on 7/22/81 as compared with cold water conditions on 3/6/82. Treatment plant personnel indicate that it is difficult to produce a settleable floc in the winter. The twelve monitorings for 12/19/80 through 5/7/82 have been separated into two categories based on raw water temperature (3°-10°C and 12°-20°C). The first four monitorings have again been eliminated due to varying treatment practices. Average cumulative percent removal for various organic parameters are presented in Table 23 for the two temperature ranges. These results clearly demonstrate that removals by sedimentation were much better under warm water conditions. For example, under cold water conditions, an average of only 20 percent of the Term TTHMs was removed by sedimentation. Under warm water conditions, an average of 54 percent of the Term TTHMs were removed by sedimentation. It is significant that the filters do the work when the water temperature is low such that overall plant peformance is about the same for the two temperature ranges. Similar temperature effects were noted earlier for the Canton water plant.

Effect of pre-disinfection/oxidation on THM formation--As discussed previously, pre-disinfection and oxidation practices varied significantly when the plant was first put into operation. Initially (April 1980) prechlorination was practiced at the old treatment plant, which is located upstream of the new treatment plant. During the first summer of operation, high levels of iron (and possibly maganese) were found in the clearwell. Chlorine was added in the rapid mix tank later that summer and early fall to oxidize these metals. Later (October 1980), chlorine was replaced by chlorine dioxide when these facilities became available. No oxidants are required after fall overturn, which usually occurs in October. By the spring of 1981, facilities for feeding potassium permanganate ($KMnO_4$) to the rapid mix tank were installed. Since that time, $KMnO_4$ has been used exclusively for oxidation of metals when required. A small dosage of chlorine

TABLE 22. AVERAGE REMOVALS BY THE ONEIDA WATER TREATMENT PLANT (12/19/80 - 5/7/82) (n=12)

Parameter	Cumulative Percent Removal -- Settled	Cumulative Percent Removal -- Filtered
Total UV_{254} Abs.	27 (20)	82* (4)
NPTOC	37* (19)	71* (14)
Term TTHM	34 (22)	68 (7)

* n = 11

TABLE 23. EFFECTS OF WATER TEMPERATURE ON PERFORMANCE OF THE ONEIDA WATER TREATMENT PLANT (12/19/80 - 5/7/82) (n=12)

Parameter	Temp 3°-10° C (n=7)		Temp 12°-20°C (n=5)	
	% Removal Settled+	% Removal Filtered‡	% Removal Settled+	% Removal Filtered‡
Total UV_{254} Abs.	16 (13)	80* (5)	42 (18)	83 (4)
NPTOC	34* (11)	73* (18)	40 (28)	68 (19)
Term TTHM	20 (16)	65 (6)	54 (11)	74 (5)

* n = 6

+ Cumulative removal: coagulation-flocculation-sedimentation

‡ Cumulative removal: coagulation-flocculation-sedimentation-filtration

( ) Standard Deviation

Notes: 1) Negative removals assumed zero for computation of averages and standard deviations;

2) 100 percent UV_{254} absorbance removal for 10/9/81 not used.

(0.7-1.1 mg/L) is still applied continuously on the top of the filters.

The type and dosage of pre-disinfectant and/or oxidant used had a significant effect on Inst TTHM levels in the finished water. Inst TTHM levels for samples taken from the clearwell effluent are summarized in Table 24 as a function of pre-disinfection and/or oxidation practice. When prechlorination was practiced, high levels of Inst TTHMs (134-148 μg/L) were found in the finished water, as shown by the data for April and September of 1980 (see Table 21). When chlorine dioxide was used (October 1980), production of THMs in the plant was reduced substantially to 57 μg/L. Since the elimination of prechlorination (rapid mix tank), finsihed water Inst TTHMs have consistently been below the maximum contaminant level (MCL) of 0.10 mg/L (see Tables 21 and 24).

TABLE 24. EFFECT OF PRE-DISINFECTION/OXIDATION PRACTICE ON THM FORMATION IN THE ONEIDA WATER TREATMENT PLANT

Pre-Oxidant/ Disinfectant	Dosage Range (mg/L)	Number of Monitorings	Inst TTHMs (μg/L)
Cl_2	4.2-4.9	2	141
*ClO_2	0.7	1	57
*$KMnO_4$	0.12-0.7	6	35
*None	0	6	20

* 0.7-1.1 mg/L Cl_2 on top of filters

Distribution system trihalomethanes--Samples for Inst TTHMs in the distribution system were collected and analyzed for two reasons. First, EPA regulations apply to samples collected at various points in the distribution system. Second, substantial THM formation may occur in distribution systems if a long detention time exists. This is particularly relevant with respect to the Oneida water system since the treatment plant is located approximately 20 miles from the City of Oneida. At the current average flow rate of approximately 10.4 ML/d (2.75 MGD), the mean hydraulic detention time is 10.5 hours for the plant (4.4 hours in clearwell) and 15 hours for the transmission main to the city. Additonal detention time takes place in the distribution system in Oneida.

Inst TTHM samples were collected at three points - Point 5, treatment plant finished water (clearwell effluent); Point 6, Oneida Towers; and Point 7, Stockbridge pumping station. These sampling locations were described earlier. In addition to these three distribution system samples, a sample of finished water was collected and held at 20°C for 7 days and then quenched with sodium sulfite. This sample, referred to as the seven day stored sample, is indicative of the maximum TTHM concentration that could be formed at 20°C in the distribution system if additional chlorine were not added.

The results for 12 sampling dates are presented in Table 25. For each sample temperature, pH, and free chlorine were measured at the time of sample collection. The highest Inst TTHM levels were found early in the study when prechlorination was being practiced. Since that time, TTHM levels in the distribution system have consistently been less than the MCL of 0.10 mg/L.

The three distribution system samples for each date have been averaged, as would be done to comply with EPA THM monitoring regulations. The results are presented in Table 26. At the bottom of this table, averages for all dates, and also for 1980 alone and 1981-1982 are presented. Distribution system Inst TTHM levels were high in 1980 (129 µg/L average), due primarily to prechlorination. Since this was eliminated, distribution system Inst TTHM levels have been reduced substantially (42 µg/L average for 1981-1982). The 1981-1982 standard deviation is also much lower, indicating more consistent water treatment plant operation.

TABLE 25. TRIHALOMETHANE FORMATION IN THE ONEIDA DISTRIBUTION SYSTEM

Date	Location Point	Temp. (°C)	pH	Free Cl_2 (mg/L)^2	INST TTHM (μg/L)
04/10/80	5	9	8.2	2.7	149
04/11/80	6	NA	7.6	1.3	139
04/11/80	7	NA	8.5	1.5	118
04/10/80	7 day stor.	20	NA	NA	199
06/03/80	5	16	9.2	3.0	88
06/04/80	6	NA	7.6	1.1	124
06/04/80	7	NA	8.1	1.4	114
06/03/80	7 day stor.	20	NA	<0.1	211
09/02/80	5	22	8.6	2.8	134
09/03/80	6	24	8.2	1.0	211
09/03/80	7	24	8.0	1.4	221
09/02/80	7 day stor.	20	NA	<0.1	190
10/14/80	5	15	8.3	2.4	57
10/15/80	6	14	7.6	NA	NA
10/15/80	7	13	7.5	1.5	108
10/14/80	7 day stor.	20	NA	<0.1	167
12/19/80	5	6	7.4	2.3	43
01/02/81	6	5	7.4	0.8	33
01/02/81	7	5	8.0	1.5	57
12/19/80	7 day stor.	20	NA	<0.1	100
01/30/81	6	NA	7.1	1.4	33
01/30/81	7	NA	8.0	1.4	29
02/16/81	5	6	7.2	2.0	12
02/19/81	6	7	7.6	0.8	21
02/19/81	7	7	8.0	1.4	35
02/16/81	7 day stor.	20	NA	<0.1	NA
04/20/81	5	9	7.4	2.3	27
04/22/81	6	NA	NA	NA	44
04/22/81	7	NA	NA	NA	66
04/20/81	7 day stor.	20	NA	<0.1	80
05/20/81	5	13	7.6	2.5	37
05/21/81	6	NA	NA	NA	62
05/21/81	7	NA	NA	NA	78
05/20/81	7 day stor.	20	NA	<0.1	NA

(continued)

TABLE 25. (continued)

Date	Location Point	Temp. (°C)	pH	Free Cl_2 (mg/L)	INST TTHM (μg/L)
06/25/81	5	19	7.0	3.2	19
06/20/81	6	15	7.1	0.5	71
06/20/81	7	15	8.0	1.5	93
06/25/81	7 day stor.	20	NA	0.2	92
10/09/81	5	13.5	7.4	2.2	36
10/09/81	6	16	NA	1.0	60
10/09/91	7	15	NA	1.5	70
10/09/81	7 day stor.	20	NA	0.4	114
03/06/82	5	5	7.4	2.2	10
03/11/82	6	7	7.6	1.3	18
03/11/82	7	7	8.0	1.1	26
03/06/82	7 day stor.	20	NA	0.9	52

Point 5 Plant finished water
6 Oneida Towers
7 Stockbridge pumping station

NA Not Available

TABLE 26. AVERAGE ONEIDA DISTRIBUTION SYSTEM INST TTHMs (POINTS 5, 6, and 7)

Date	Average Inst TTHM (μg/L)	Comments
4/11/80	135*	Pre-chlorinating at old plant (4.9 mg/L)
06/04/80	109*	2.9 mg/L Cl_2 top of filters
09/30/80	189*	Pre-chlorinating in rapid mix (4.2 mg/L)
10/15/80	82	0.7 mg/L ClO_2 in rapid mix
01/02/81	44	
01/30/81	31	
02/19/81	23	
04/22/81	46	
05/21/81	59	
06/20/81	61	
10/09/81	55	
03/11/82	18	
All Dates (n=12)	71 (51)+	
1980 only (n=4)	129 (46)	
1981-1982 (n=8)	42 (16)	

* N.B.: in practice, water plants would report these TTHM data to two significant places.

+( ) Standard deviation

SECTION 7

DIRECT FILTRATION

Section 7 is organized as follows. First, principles of filtration in water treatment and applications of direct filtration are reviewed. Second, the results of jar test experiments are summarized. These jar tests screened numerous cationic polymers for use as the sole destabilizing chemical in direct filtration, and show that jar tests can be used to select polymer dosages for direct filtration. Third, the results of direct filtration pilot plant experiments for the Grasse River at Canton, N.Y. are presented. Finally, direct filtration results for the Glenmore Reservoir at Oneida, N.Y. are described.

In this research study both small scale and large scale direct filtration pilot plants were used. It is important to describe clearly the performance criteria and objectives of these pilot plant experiments. This study was concerned with both traditional measures of filter performance (filtered water turbidity, color, and head loss development) and removals of organic matter (TOC), THM precursors (TTHMFP) and UV (254 nm) absorbance (surrogate parameter for TOC and THM precursors). Table 27 summarizes pertinent features of these water quality parameters. There is a primary standard for turbidity and a secondary standard for color, but there are no standards for the other parameters. For THMs there is a primary standard (MCL of 0.10 mg/L), but it is not on the THM precursor concentration (TTHMFP).

How long were the filter experiments run, and what criteria were used for performance? The objectives and criteria depended on pilot plant scale as outlined in Table 28. As mentioned above there are no potable water standards for TOC and THM precursors. It was a major objective of this research to determine what removals could be accomplished by direct filtration, therefore no criteria for these parameters were set in advance. The small scale direct filtration experiments were designed to examine chemical filtration variables: pH, coagulant types (various cationic polymers and alum), and coagulant dosages. The influence of raw water quality on polymer dosage requirements and performance was also examined. The small scale experiments were normally operated for short periods (5-8 hrs). During operation of a filter experiment, turbidity, color, and head loss were used to judge filtration performance.

The large scale (Waterboy) experiments had different objectives (see Table 28). Turbidity and color were again used to judge filter performance during operation. In several experiments the length of the filter run was evaluated, and runs were terminated when the total head loss reached

TABLE 27. FEATURES OF CERTAIN WATER QUALITY PARAMETERS FOR POTABLE WATER TREATMENT

Turbidity	Surrogate measure of suspended particles Standard of 1 ntu Traditional parameter to measure water plant performance
Color	Surrogate measure of humic matter Secondary standard of 15 Pt-Co units No standard instrumental method of measurement Traditional aesthetic parameter
TOC	Collective or group measure of organic matter No standard or criterion
TTHMFP	Indirect measure of THM precursors No standard on precursors Standard on THMs formed
UV (254 nm) Absorbance	Surrogate measure of organics and THM precursors

TABLE 28. DESIGN OF DIRECT FILTRATION PILOT PLANT EXPERIMENTS

	Small Scale
Experimental Objectives*	(1) Primary - examine chemical variables (2) Secondary - examine physical variables
Performance Criteria	(1) Turbidity 0.2-0.4 ntu (2) Apparent color+ 15 Pt-Co units N.B. Most filter runs operated 5-8 hrs only
	Large Scale (Waterboy)
Experimental Objectives*	(1) Selected set of chemical variables depending on small scale results (2) Filtration rate and in-line vs. flocculation
Performance Criteria	(1) Turbidity 0.3 ntu (2) Apparent color+ 15 Pt-Co units (3) Selected experiments - length of filter run based on turbidity and color criteria and -2 m head loss

* See text for details

+ Spectrophotometric determination

approximately 2 m (~6.6 ft) or when breakthrough of either turbidity or color occurred.

LITERATURE REVIEW

Direct filtration is defined as a water treatment scheme wherein filtration is not preceded by sedimentation. The obvious economic advantages associated with elimination of the sedimentation process from conventional treatment have been well documented (Culp, 1977; Tate, 1977). In this section, the theory of filtration as it applies to water treatment will be discussed. Also, the applicability of direct filtration and some design considerations will be discussed.

Theory

Yao et al. (1971) have described filtration as a process consisting of at least two separate and distinct steps. The first of these steps is the transport of suspended particles from the bulk fluid to the immediate vicinity of the solid-liquid interface which occurs at the filter grain surface. This transport step is considered to consist of three components: interception, sedimentation, and diffusion. These three transport mechanisms are summed to yield what is termed the total single collector efficiency, η_T.

Equations describing the three individual transport mechanisms have been developed (Yao et al., 1971). The first mechanism, interception, occurs when a suspended particle moving with the streamlines of fluid flow comes in contact with a collector surface (filter media). This is dependent on the size of the suspended particle. The mathematical description of this mechanism is

$$\eta_I = \frac{3}{2} \left(\frac{d_p}{d_c}\right)^2 \tag{1}$$

where η_I is the single collector efficiency constituent due to interception, d_p is the suspended particle diameter, and d_c is the collector diameter.

The second transport mechanism, sedimentation, occurs when a particle with a density greater than that of water follows a trajectory which departs from the streamline and contacts a collector. The third mechanism, diffusion, occurs as a result of Brownian motion. Equations for these two mechanisms are

$$\eta_G = \frac{(\rho_p - \rho_\ell)\, g\, d_p^{\,2}}{18\, \mu\, v_o} \tag{2}$$

$$\eta_D = 0.9 \left(\frac{kT}{\mu\, d_p\, d_c\, v_o}\right)^{2/3} \quad (3)$$

where the subscripts G and D stand for sedimentation and diffusion, respectively, ρ_p is the particle density, ρ_ℓ is the liquid density, g is the gravitational constant, μ is the fluid viscosity, k is Boltzmann's constant, T is the absolute temperature and v_o is the water velocity approaching the filter surface.

To illustrate graphically the dependence of single collector efficiency on size of the suspended particles, the three transport mechanisms have been plotted as a funciton of d_p in Figure 26. The conditions used in preparing this figure were typical of those used in this research. Conditions included a temperature of 25°C, a particle density (ρ_p) of 1.01 g/cm^3, which may be representative of humic matter, a collector diameter of 1.1 mm which corresponds to the effective size of the anthracite used, and a flow velocity of 9.76 m/hr. Results indicate that single collector efficiency is at a minimum for suspended particles of 2-3 μm. Below this size, efficiency increases rapidly due to Brownian diffusion. Above this critical size, efficiency increases rapidly due to sedimentation and interception.

Once a particle has been transported to the surface of a collector, its removal depends on the second step, attachment. To mathematically describe this step, a collision efficiency factor, α, is used. Values of α range from 0 to 1 with $\alpha = 1$ corresponding to a completely destabilized suspension, such that all collisions of particles with the collector surface result in attachment (Yao et al., 1971).

The single collector efficiency, η_T, and the collision factor, α, are then incorporated into a single equation to describe the performance of a clean packed bed (Yao et al., 1971):

$$\ln \frac{C}{C_o} = -\frac{3}{2}(1-f)\, \alpha \eta_T \left(\frac{L}{d_c}\right) \quad (4)$$

where C and C_o are the effluent and influent concentrations, f is the bed porosity, L is the bed depth, and other terms are as defined previously. The above theoretical equation for clean bed filtration efficiency indicates that filtration, to a first approximation, is independent of particle concentration (Habibian and O'Melia, 1975). Coagulation theory, on the other hand, states that aggregation efficiency decreases as particle concentration decreases. Thus, the treatment of waters containing low particle concentrations by conventional coagulation and sedimentation is often very inefficient.

O'Melia and Ali (1978) have built upon this clean bed model to develop a model which considers the removal of particles by previously retained particles. This model is used to explain the "ripening" of a filter bed when it is first put into operation. A second collision efficiency factor (α_p) is used to account for successful collisions between suspended particles and

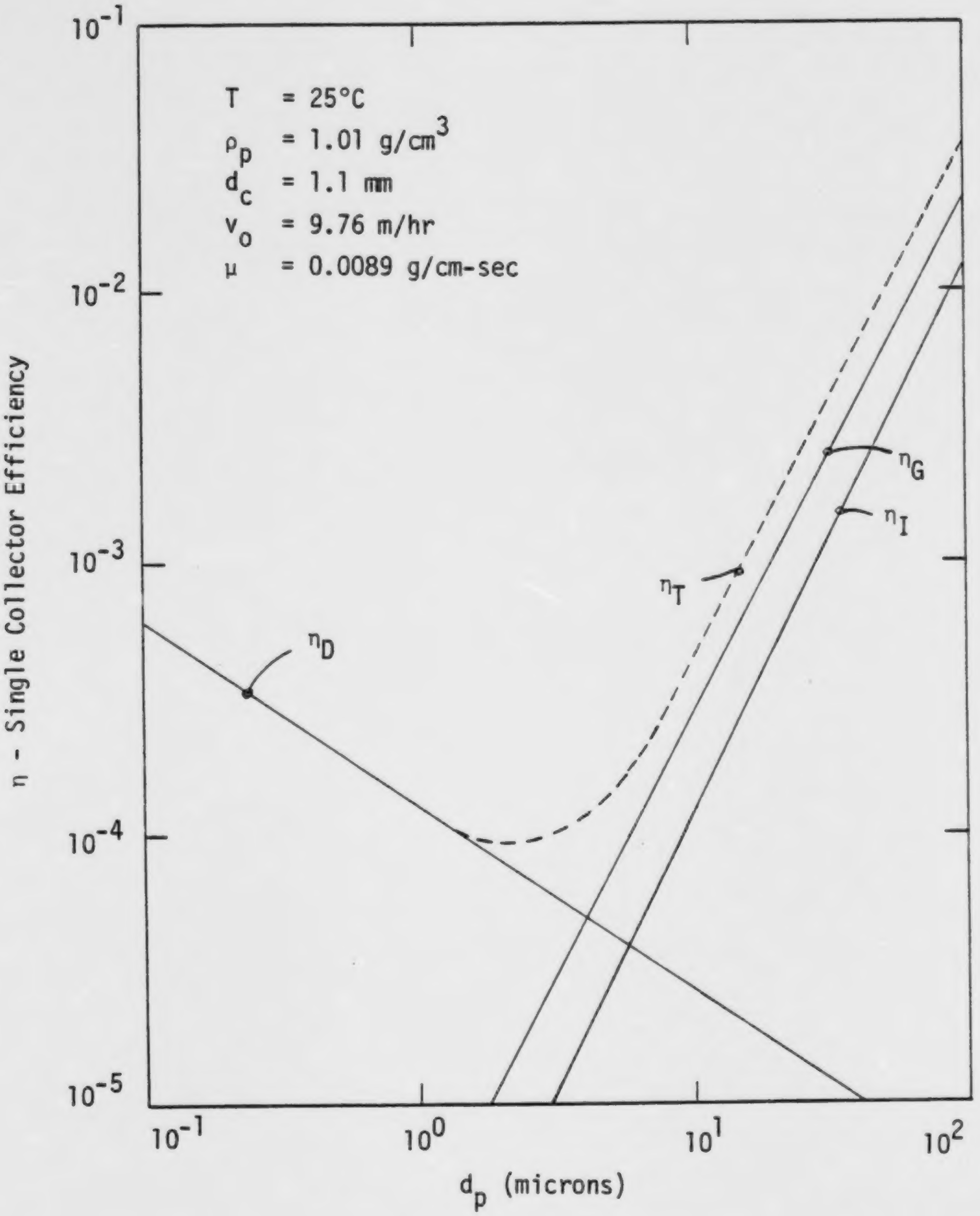

Figure 26. Single collector efficiency as a function of suspended particle diameter.

previously retained particles. This model also includes a head loss equation as a function of particle removal.

O'Melia and workers (Habibian and O'Melia, 1975; O'Melia and Ali, 1978) have confirmed with experiments the theoretical effects of suspended particle size on filter efficiency. Figure 27a shows that 1.0 μm size suspended particles have the poorest removal compared to 0.1 μm and 7.6 μm size particles. This agrees with the theory regarding single collector efficiency shown in Figure 26. Figure 27b shows their results for head loss development as a function of suspended particle size. The results indicate that head loss development varies inversely with the size of the applied particles. This implies that providing a flocculation period to aggregate small particles into larger particles will retard head loss development. This effect has been confirmed by Glaser and Edzwald (1979).

Practical Considerations

The need for chemical addition to destabilize the colloidal particles prior to filtration has been demonstrated by several researchers (Yao et al., 1971; Habibian and O'Melia, 1975; Boyd and Ghosh, 1975; Glaser and Edzwald, 1979). Alum, iron slats, and cationic polyelectrolytes are frequently used for destabilizing purposes. A review of the literature reveals that no consistent trends exist in mixing times or energy inputs for either the rapid mixing or flocculation processes. However, a survey conducted by the AWWA Filtration Committee (1980) found that those plants with the fewest problems had good control of these processes. In treating waters containing submicron particles such a humic substances, flocculation has been found to retard head loss development due to a reduction in the total surface area of particles retained in the filter bed (Glaser and Edzwald, 1979).

Alum has been used extensively in the past as the primary coagulant in conventional treatment schemes and also in most of the early direct filtration plants. Nonionic polymers at low dosages (0.05 to 0.5 mg/L) have often been used as filter aids in conjunction with alum to prevent premature turbidity breakthrough (Hutchinson, 1976).

The use of cationic polymers as primary coagulants has increased recently, particularly in pilot plant studies (AWWA Filtration Comm., 1980). The use of polymers is desirable because dosages are usually much less than alum (Culp, 1977). Thus the solids loading to the filter is reduced, and longer filter runs are expected. Also filter wastewater volumes would be reduced, and the polymer wastewaters (sludge) are normally easier to treat than those containing metal salts. Finally, problems with pH and alkalinity adjustments would be reduced.

The filter media used in direct filtration is almost always a reverse-graded dual media arrangement of anthracite and sand. The development of this type of filter over the past two decades has made direct filtration possible due to the large floc storage capacity of the upper layer of anthracite. Typical depths are 51-61 cm and 25-33 cm for the anthracite and sand, respectively. Typical effective sizes are 1.0-1.2 mm for anthracite and 0.4-0.5 mm for sand (Tate et al., 1977; Trussell et al., 1980;

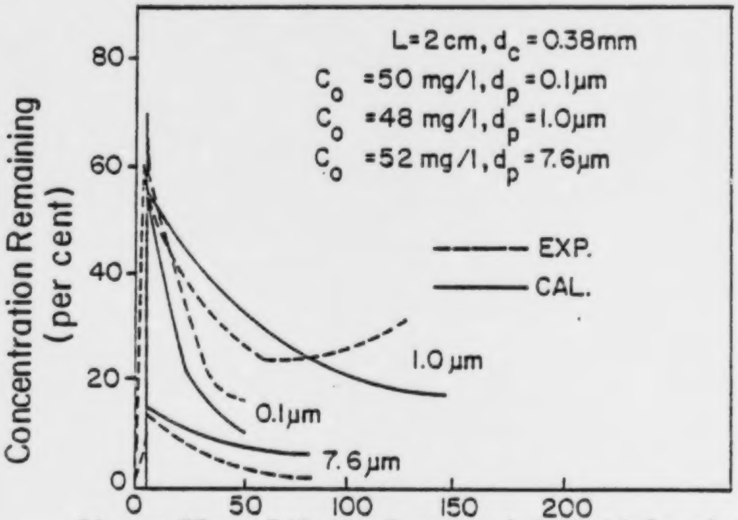

Figure 27a. Effect of suspended particle size on filter efficiency

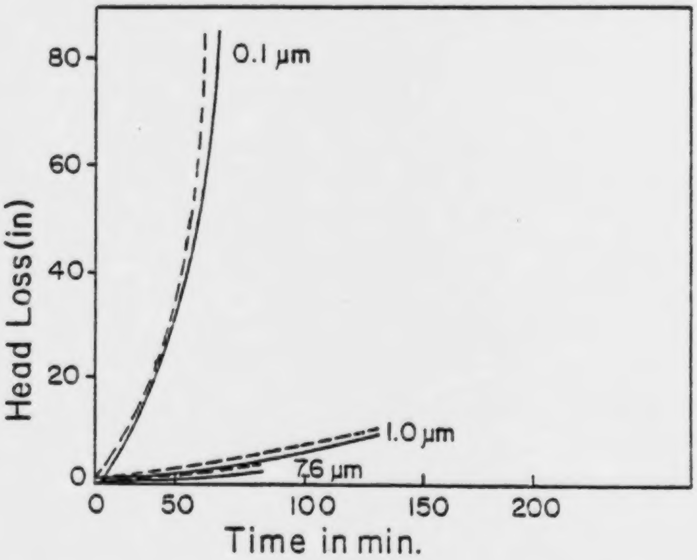

Figure 27b. Effect of suspended particle size on head loss development during filtration (from Habibian and O'Melia, 1975).

Hutchinson, 1976). Typical design filtration rates range from 9.8 to 14.5 m/hr (Culp, 1977; AWWA Filtration Comm., 1980). Higher backwash rates than used in conventional filtration plants and the use of surface wash have been reported in direct filtration practice (AWWA Filtration Comm., 1980).

JAR TESTS

Jar tests were used to screen cationic polymers and to select dosages, as will be demonstrated, for direct filtration experiments.

Polymer Screening

During the first year of the project a large number of cationic polymers were screened for their ability to destabilize turbidity and color using jar test techniques. The polymers tested were presented in Section 4 and are listed in Table 1.

The following conclusions were drawn from a series of jar test studies on the Grasse River and Glenmore Reservoir waters. For the Grasse River which is a highly colored, low turbidity water.

- Good destabilization was achieved with Betz 1190, Magnifloc 572C, and Magnifloc 573C.
- Fair to good destabilization was achieved with Betz DK-724; Magnifloc 521C, 581C, 585C, and 587C; Cat Floc T, T-1, 21, and 121; and Nalco 8101.
- Poor or no destabilization was achieved with Magnifloc 515C.

For Glenmore Reservoir, which is a low turbidity water, the following conclusions were made.

- Good destabilization was achieved with Betz 1190; Magnifloc 572C, 573C, and 581C.
- Fair to good destabilization was achieved with Cat Floc T, T1, 21, and 121; Magnifloc 521C, 585C, 587C; Nalco 8101; and Betz DK-724.
- Poor or no destabilization was achieved with Magnifloc 515C.

It is important to note that jar tests can be used to screen the relative destabilizing ability of various cationic polymers; however, actual filtration experiments are needed to evaluate the ability of the polymers to remove turbidity, color, and THM precursors in direct filtration applications. As shown next, however, jar tests can be used to select coagulant dosages for direct filtration.

Selection of Direct Filtration Coagulant Dose

Several investigators (Yao *et al.*, 1971; Habibian and O'Melia, 1975; Glaser and Edzwald, 1979) have demonstrated the utility of batch jar tests in selecting coagulant dosages for filtration. Analogous underdosing and overdosing phenomena have been shown to occur between the coagulation performance in a jar test and filtration performance. These concepts are illustrated below.

Raw water for the jar test was collected from the Grasse River on the same day a filter run was conducted. The jar test was performed just prior to the filter run. In this example, the turbidity and apparent color of the raw water were 3.0 ntu and 65 Pt-Co units, respectively. The water was dosed with a cationic polymer, Magnifloc 573C, over the range of 0.5-8.0 mg/L.

Figure 28a shows the jar test results. At low dosages (0-2 mg/L) it is evident that insufficient amounts of polyelectrolyte have been added to destabilize the humic material present in the raw water as reflected in high measurements of true color. A sharp decline in true color occurs at a dosage of approximately 4 mg/L indicating destabilization of humic matter, and this dosage is arbitrarily called an "optimum" jar test dose. At dosages much greater than 4 mg/L, overdosing may occur. Although not readily apparent by the true color data, restabilization of the particles would be expected due to excessive amounts of polymer. This will be demonstrated later with electrophoretic mobility (EPM) data for a synthetic humic water.

During the filter experiment, dosages were chosen to represent jar test underdosing (2 mg/L), "optimum" (4 mg/L and perhaps up to 8 mg/L), and overdosing (perhaps 8 mg/L and 12 mg/L). Each dosage was held for approximately 1.5 hours. Other experimental conditions included a filtration rate of 4.88 m/hr, no adjustment in raw water pH (pH 6.7), a temperature of 10°C, and the in-line direct filtration mode.

Figure 28b shows the results of the filter run. In agreement with the jar test prediction, good filtration performance occurred at a polymer dose of 4 mg/L. Removals of color reached approximately 85 percent with effluent turbidities as low as 0.25 ntu. A brief shutdown of the polymer feed system to alter the system for feeding higher dosages caused performance deterioration for a brief period (shown on the graph at the beginning of the 8 mg/L polymer dose). The system recovered indicating that 8 mg/L is still a good polymer dose, but perhaps a slight overdose. When the polymer dose was increased to 12 mg/L, overdosing clearly occurred as indicated by the turbidity values being greater than 0.8 ntu.

To supplement these results and to determine a mechanism of destabilization, a jar test was conducted using a 10 mg/L humic acid (Aldrich Chem. Co.) water buffered with 0.2 M $NaHCO_3$ at pH 6.3. Magnifloc 573C was used as the coagulant over a wide range of dosages. In this jar test, EPM measurements were made and the results are shown in Figure 29. At low dosages (0-6 mg/L) underdosing is observed whereby an insufficient amount of positively charged polymer has been added to achieve particle destabilization. This is reflected in the UV and color data as well as the negative EPM values. At a dosage of 8 mg/L, the jar test "optimum" for UV and color, the mobility is close to zero with a slight negative charge. At this point, enough cationic polymer has been added to neutralize the charge of the humic matter. Charge neutralization is important, but the mechanism is different than that traditionally described for cationic polymers adsorbing on colloidal solid surfaces. The mechanism described by Glaser and Edzwald

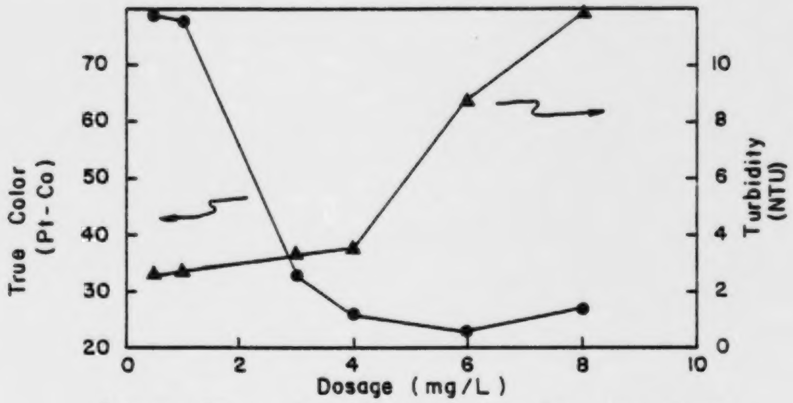

Figure 28a. Jar test results for raw water used in exp. C21A.

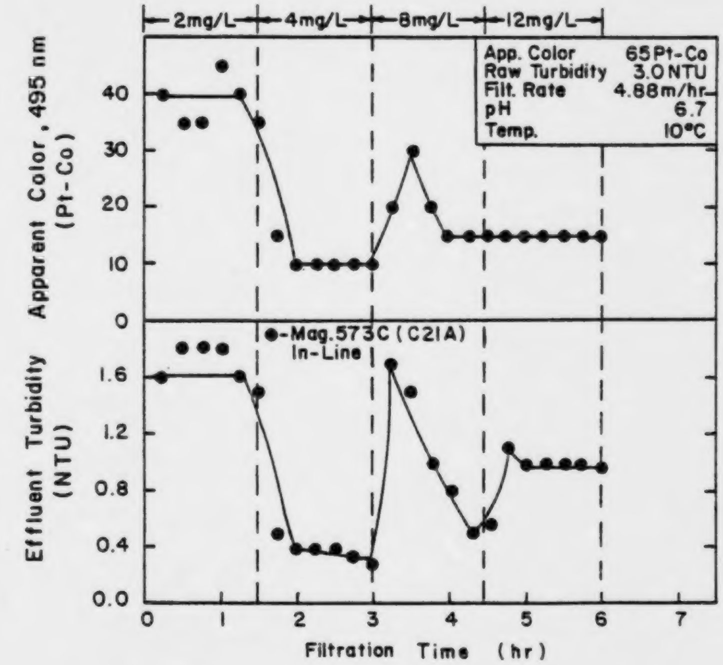

Figure 28b. Filter run results for exp. C21A.

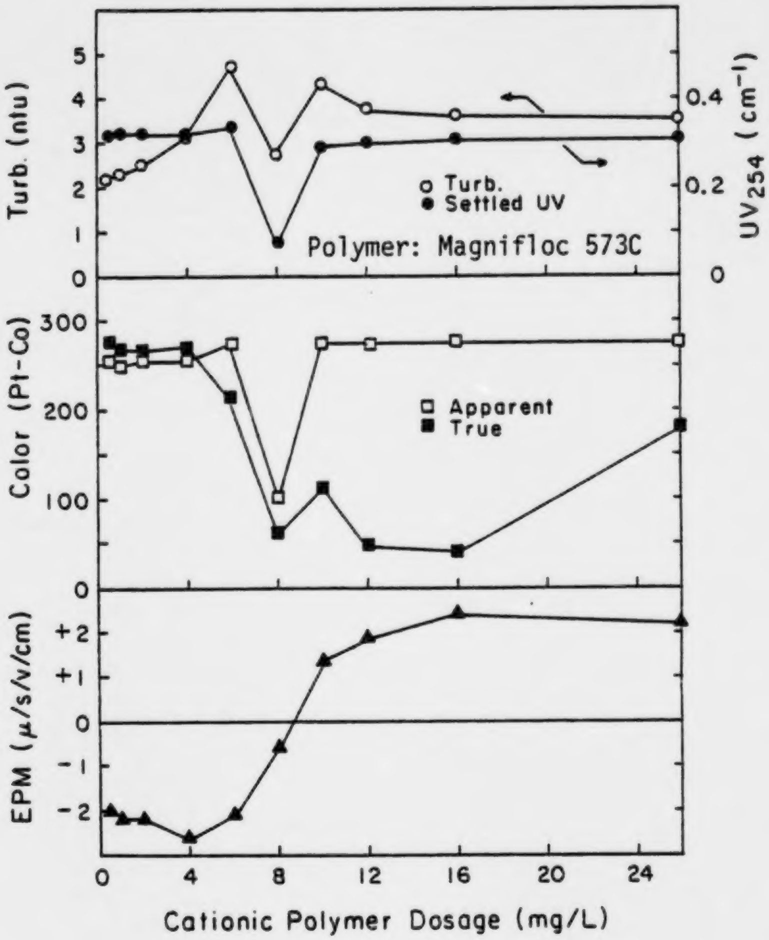

Figure 29. 10 mg/L humic acid (pH 6.3) jar test results and electrophoretic mobility determinations.

(1979) for coagulation of humic substances by cationic polymers is proposed. Aggregates (precipitates of humic matter and cationic polymer) are formed from a crosslinking between the negatively charged humic macromolecules and the cationic polymers. Overdosing is observed at dosages greater than 8 mg/L. Here, the suspension of particles are restabilized as indicated by the increase in UV and apparent color. Charge reversal occurs with excess polymer addition as indicated by the positive EPM values.

Summary

Jar tests were used to screen the ability of cationic polymers to destabilize humic and colloidal material in the Grasse River and Glenmore Reservoir. Based on the results, several polymers were selected for examination in direct filtration experiments (see Table 1). Jar tests can also be used to select coagulant dosages for direct filtration. The "optimum" dose for coagulation based on jar tests is an "optimum" dose for direct filtration. Underdosing and overdosing occurs in direct filtration and can be predicted from jar tests.

Three cationic polymers (Betz 1190, Magnifloc 572C and Magnifloc 573C) were tested in both large scale (Waterboy) and small scale filter experiments. All three are polyquaternary amines. Charge density measurements are summarized in Table 29. The charge on the polymers was measured by the colloid titration technique (Kawamura and Hanna, 1966; Wang and Shuster, 1975). For the pH range indicated, their charge is independent of pH. It is noted that Betz 1190 and Magnifloc 572C have the same charge on a solids basis whereas Magnifloc 573C has a slightly higher cationic charge density.

TABLE 29. CHARGE DATA FOR THE CATIONIC POLYELECTROLYTES

	Solids Content (%)	pH	Charge* (meq/g)	Charge+ (meq/g solids)
Betz 1190	43.4	4.0	3.46	7.98
		5.0	3.46	7.98
		6.0	3.46	7.98
		7.0	3.46	7.98
Magnifloc 572C	51.7	4.0	4.14	8.01
		5.0	4.11	7.95
		6.1	4.11	7.95
		7.0	4.06	7.86
Magnifloc 573C	50.4	4.0	4.30	8.55
		5.0	4.30	8.55
		6.1	4.30	8.55
		7.0	4.15	8.23

* Commercial product basis
+ Dry solids basis

DIRECT FILTRATION PILOT PLANT EXPERIMENTS AT CANTON

This section is organized by first reporting the results of small scale pilot plant experiments conducted early on in the project. This is reported under the subsection labeled Initial Phase. Next, filter experiments involving the Waterboy pilot plant (large scale pilot plant) are reported along with some alum experiments conducted on the small scale pilot plant. These results are reported in the subsection labeled Final Phase.

Initial Phase

Numerous small scale experiments were conducted in the initial study phase of the project. These experiments were conducted between July 1980 and March 1981. A summary of operating conditions is listed in Table 30. Only the experiments involving cationic polymers are discussed here; the alum experiments are incorporated into the discussion dealing with the final phase results.

These experiments served several purposes:

(1) To verify that jar tests could be used to choose polymer dosages for direct filtration,

(2) To evaluate several polymers,

(3) To evaluate seasonal raw water quality changes on polymer dosage requirements and filtration performance,

(4) To evaluate polymer precoating of the filter media,

(5) To examine direct filtration with and without a flocculation period,

(6) To examine filter performance at filtration rates of 4.88 and 9.76 m/hr.

Typical Results--

Typical results from two experiments evaluating two of the cationic polymers are shown in Figure 30. These experiments were conducted in the summer when the Grasse River contains high levels of organic matter and apparent color. The NPTOC was 9.8 mg/L and TTHMFP was 732 µg/L (see 8/5/80, Table 12). Because of this, high polymer dosages (9 mg/L) were needed to destabilize the organic matter and color. Filtered water turbidities were generally 0.1-0.2 ntu and color was 10-15 Pt-Co units. Based on traditional measures of filtration performance, the results demonstrate that cationic polymers can treat highly colored waters by direct filtration.

Figure 31 shows typical results for experiments conducted during the winter for the same two polymers. Here the filter experiments were conducted under winter water conditions (see 1/19/81, Table 12) and at a temperature of 6.5°C. At this time of the year the Grasse River contains relatively low levels of organic matter and apparent color. The NPTOC and TTHMFP were 3.5 mg/L and 232 µg/L. Due to the lower levels of color and organic matter, the required polymer dosages were only 3 mg/L. The results show excellent filter performance.

TABLE 30. SUMMARY OF SMALL SCALE FILTER EXPERIMENTS (INITIAL PHASE, CANTON, N.Y.)

No.	Date	Coagulant	Dosage (mg/L)	pH	Flow (mL/min)	Filt. Rate (m/hr)	Floc. Period (min)	Temp. (°C)
C01A	07/14/80	None	0	5.5-6.0	253.0	9.76	*	21.0
C01B	07/14/80	1190	8-9.1	5.5-6.0	253.0	9.76	*	21.0
C02A	07/14/80	1190	5-12	5.5-6.0	253.0	9.76	*	21.0
C02B	07/14/80	1190	5-12	5.5-6.0	253.0	9.76	*	21.0
C03B	07/24/80	1190	8-9.5	Varied	253.0	9.76	*	22.0
C04A	07/24/80	1190	8.5	5.5-6.0	253.0	9.76	*	22.0
C04B	07/24/80	1190	8.5	5.5-6.0	253.0	9.76	12	22.0
C05A	07/30/80	572C	9	5.5-6.0	253.0	9.76	*	23.0
C05B	07/30/80	573C	9	5.5-6.0	253.0	9.76	*	23.0
C06A	07/30/80	585C	12	5.5-6.0	253.0	9.76	*	23.0
C06B	07/30/80	581C	10	5.5-6.0	253.0	9.76	*	23.0
C07A	08/05/80	572C	9	5.5-6.0	253.0	9.76	12	23.0
C07B	08/05/80	573C	9	5.5-6.0	253.0	9.76	12	23.0
C08A	08/05/80	Cat Floc T	10	5.5-6.0	253.0	9.76	12	23.0
C08B	08/05/80	1190	10	5.5-6.0	253.0	9,76	12	23.0
C09A	08/19/80	573C	12.2	5.5-6.0	253.0	9.76	24	19.0
C10A	08/19/80	573C	12.2	5.5-6.0	126.5	4.88	24	19.0
C11A	10/10/80	572C	8.3	5.5-6.0	253.0	9.76	*	14.0
C11B	10/10/80	573C	8.3	5.5-6.0	253.0	9.76	*	14.0
C12A	10/10/80	572C	8.5	5.5-6.0	126.5	4.88	24	14.0
C13A	10/31/80	572C	8.5	5.5-6.0	253.0	9.76	24	12.0
C14A	01/19/81	573C	3	5.5-6.0	126.5	4.88	*	6.5
C14B	01/19/81	572C	3	5.5-6.0	126.5	4.88	*	6.5
C15A	01/19/81	Alum	10-15	Varied	126.5	4.88	*	9.0
C15B	01/19/81	1190	3	5.5-6.0	126.5	4.88	*	7.5
C16A	01/26/81	573C	3	5.5-6.0	126.5	4.88	24	7.5
C17A	01/26/81	Alum	7-10	5.2-5.5	126.5	4.88	24	10.0
C18A	03/16/81	573C	4	5.5-6.0	253.0	9.76	*	8.0
C18B	03/16/81	573C	4	5.5-6.0	126.5	4.88	*	7.0
C20A	03/23/81	Alum	12.5	5.0-5.6	126.5	4.88	*	12.0
C20B	03/23/81	Alum	12.5	5.0-5.6	126.5	4.88	*	11.5

* No flocculation tank

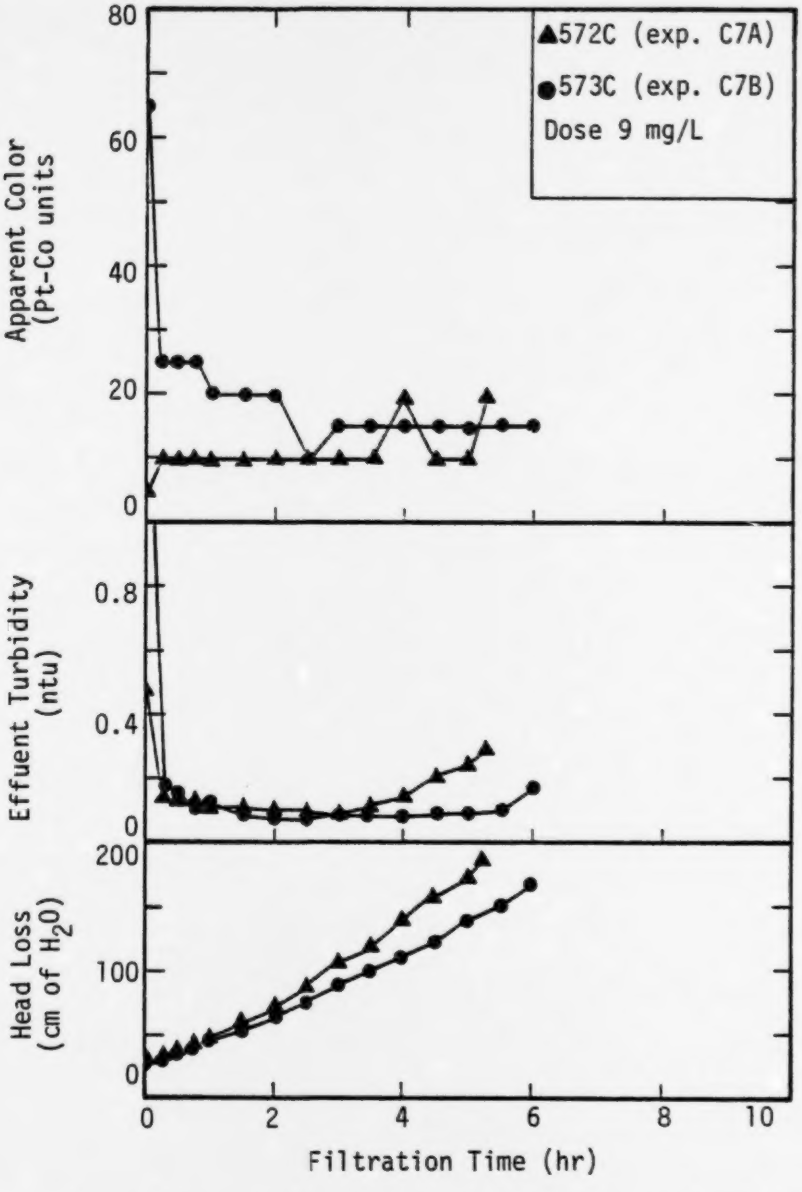

Figure 30. Apparent color, turbidity, and head loss results for pilot plant experiments C7A and C7B.

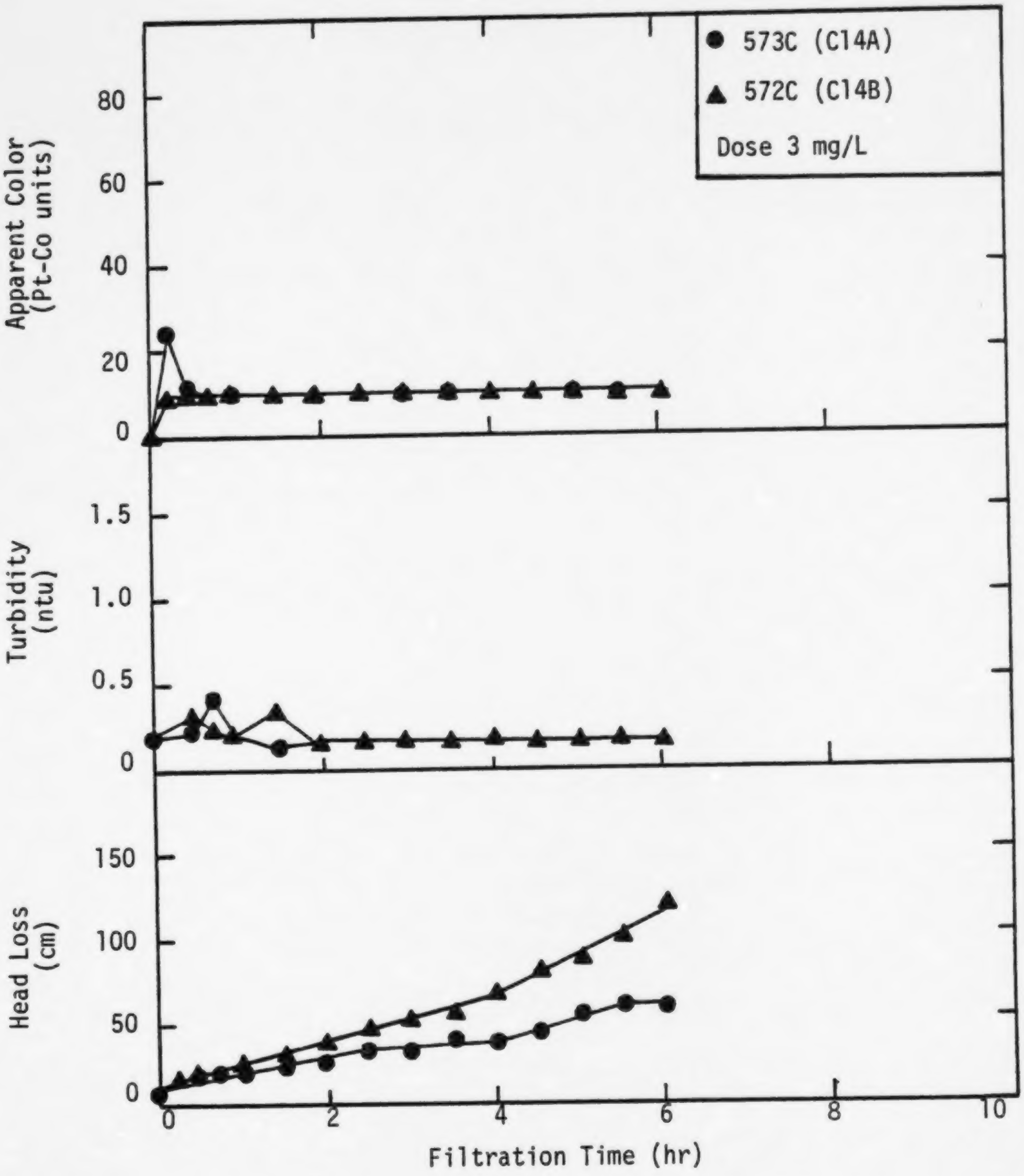

Figure 31. Apparent color, turbidity, and head loss results for pilot plant experiments C14A and C14B (temp. 6.5°C).

Major Findings--

Typical results were presented above to illustrate that cationic polymers can treat a humic water such as the Grasse River by direct filtration. Here, the major findings of the initial phase (small scale) experiments are summarized.

(1) Jar tests can be used to select polymer dosages, this concept was discussed in the Jar Test subsection.

(2) Cationic polymers can be used to treat a highly colored water by direct filtration. Filtered water turbidities of 0.2 ntu and apparent color of 15 Pt-Co units can be achieved.

(3) Good results were obtained with Betz 1190 and Magnifloc 572C, 573C, and 585C polymers. Betz 1190, Nagnifloc 572C, and Magnifloc 573C were selected for evaluation in the large scale (Waterboy) studies.

(4) For the Grasse River, precoating of the filter media with cationic polymer is not needed. Good results were obtained with and without a precoat.

(5) Good filtration performance was obtained at filtration rates of 4.88 and 9.76 m/hr. A flocculation period increased filter times by decreasing head loss development compared to in-line filtration. The effects of filtration rate and in-line filtration vs. filtration with flocculation were selected for further study in the large scale studies.

(6) Good filtration performance was obtained at low water temperatures - as low as 6.5°C.

(7) Cationic polymer dosage requirements depend on raw water concentrations of organic matter as measured by TOC, UV absorbance, or apparent color. Table 31 shows that Magnifloc 573C dosage requirements varied from 3 to 4 mg/L in the winter and spring, to 9-12 mg/L in the summer.

(8) The small scale studies showed that cationic polymers reduce THM precursors by approximately 40 percent - see Table 31. Removals of UV and TOC are approximately 60 and 40 percent. Evaluation of THM precursor, NPTOC and UV removals was selected for further study in the large scale experiments.

TABLE 31. SUMMARY OF SMALL SCALE RESULTS FOR MAGNIFLOC 573C FOR DIFFERENT SEASONS (GRASSE RIVER AT CANTON, N.Y.)

Season	Raw Water Quality					573C	Percent Removals		
	Turb. (ntu)	App. Color (Pt-Co)	UV (cm^{-1})	NPTOC (mg/L)	TTHMFP (μg/L)	Dose (mg/L)	UV	NPTOC	TTHMFP (5-day)
Summer	2-2.3	100-140	0.46-0.54	9.8-11.8	689-743	9-12	52-65	32-44	37-39
Winter	2-2.6	60	0.15-0.16	3.2-3.5	232-254	3	60-65	32-42	33-44
Spring	2.1	50	0.16	3.4	278	4	50-64	30-50	32-48

Final Phase

The following operating variables were examined: coagulant type, coagulant dose, pH, in-line filtration vs. direct filtration with flocculation, and filtration rate. In addition, raw water quality and water temperature effects were evaluated. Table 32 summarizes the operating conditions for each experiment. A total of 29 pilot plant experiments were conducted. The last 4 were run on the small scale pilot plant, all others with the Waterboy (large scale) facility. Raw water quality conditions are listed in Table 12.

First, the results using polymers in direct filtration are presented; then results for alum are presented.

Performance Using Polymers--

Three cationic polyelectrolytes were evaluated. The polymers Betz 1190, Magnifloc 572C, and Magnifloc 573C had previously been shown (Initial Phase) to work in treating the highly colored Grasse River by direct filtration.

Results of three similar experiments (C03P, C05P, C07P) are presented in Figure 32 and compare the three polymers. Excellent performance for all three polymers and little performance variation during their respective runs were achieved in terms of turbidity and color. Although head loss accumulation for the three was approximately the same, turbidity breakthrough brought the run using Betz 1190 to a premature termination. A possible explanation for this stems from the raw water conditions. Referring to Table 12, it is evident that the raw water quality when using Betz 1190 (Exp. C03P) was worse than the other two as reflected in total UV (254 nm) measurements of 0.51, 0.45, and 0.465 cm^{-1} for Exps. C03P, C05P, and C07P, respectively. Although a greater dosage of Betz 1190 was added to the water, each polymer has different charge densities and dosages must be considered on the basis of the actual positive charge added per liter. Table 33 shows that the dosages for all three experiments were approximately equal at 0.04 meq/L of positive charge. Therefore, due to the raw water conditions it is assumed that 12 mg/L Betz 1190 (product dosage) was probably a slight underdose thus causing premature breakthrough.

The three polymers were also studied for their influence on the removal of organic material which act as THM precursors. Figure 33 presents the results on the basis of normalized effluent values of 7-day total trihalomethane formation potential (TTHMFP), non-purgable total organic carbon (NPTOC) and total UV (254 nm). As illustrated, similar removals were obtained using the different polymers.

The three polymers are similar, therefore, as expected, direct filtration performance is also similar. Magnifloc 573C, however, did seem to produce slightly longer filter runs with no signs of performance deterioration in the experiments mentioned above and in another set of experiments which (C02P, C04P, C06P) compared the three polymers. For this reason, Magnilfoc 573C was chosen as the sole polymer coagulant for more extensive studies.

TABLE 32. SUMMARY OF FILTER EXPERIMENTS (FINAL PHASE, CANTON, N.Y.)

No.*	Date	Coagulant	Dosage (mg/L)	pH	Flow (L/s)	Filt. Rate (m/hr)	Floc. Period (min)	Temp (°C)	Static Mixers G (sec^{-1})	Floc G (sec^{-1})
C01P	6/22/81	1190	10	Unadjust	1.01	9.76	-	22.0	1672	-
C02P	6/25/81	1190	13	6.0	1.01	9.76	-	22.0	1668	-
C03P	6/30/81	1190	12	5.5-5.9	1.01	9.76	9.2	21.0	1677	21.7
C04P	7/02/81	572C	8.1-12	6.1	1.01	9.76	-	23.0	1716	-
C05P	7/08/81	572C	10	6.0	1.01	9.76	9.2	25.0	1769	22.8
C06P	7/13/81	573C	9	6.2-6.4	1.01	9.76	-	23.5	1731	-
C07P	7/15/81	573C	9	6.0-6.2	1.01	9.76	9.2	23.5	1698	21.9
C08P	7/17/81	573C	9	7.3,6.5	1.01	9.76	9.2	23.0	1722	22.2
C09P	7/21/81	573C	9	Unadjust	0.50	4.88	18.4	23.5	612	22.2
C10P	7/23/81	573C	10.5	Unadjust	0.50	4.88	-	22.0	595	-
C11P	7/27/81	573C	9.4	Unadjust	1.45	14.03	-	23.5	3197	-
C12P	7/29/81	573C	9	Unadjust	1.51	14.64	6.1	20.0	3063	21.2
C15P	8/11/81	573C	5-27	Unadjust	1.01	9.76	-	22.5	1693	-
C17P	8/16/81	573C	15.3	Varied	1.01	9.76	-	19.5	1630	-
C18P	8/19/81	573C	20	Varied	1.01	9.76	-	19.5	1636	-
C19P	10/08/81	573C	Varied	Unadjust	1.01	9.76	-	9.0	1422	-
C22P	10/20/81	573C	8	Unadjust	1.01	9.76	9.2	8.5	1404	18.2
C23P	10/22/81	Alum	20	5.5-5.6	0.50	4.88	18.4	7.0	NA	88
C21A	1/04/82	573C	Varied	6.7	126.5[+]	4.88	-	10.0	NA	-
C23A	1/13/82	573C	5	6.9-7.1	126.5[+]	4.88	24.0	6.5	NA	NA
C24A	1/18/82	Alum	15	5.5-5.7	126.5[+]	4.88	-	6.0	NA	-
C25A	2/17/82	Alum	14	5.5	126.5[+]	4.88	48.0	10.0	NA	NA

NA - not available

* - P designation is Waterboy experiment
A designation is small scale experiment

[+] - in mL/min

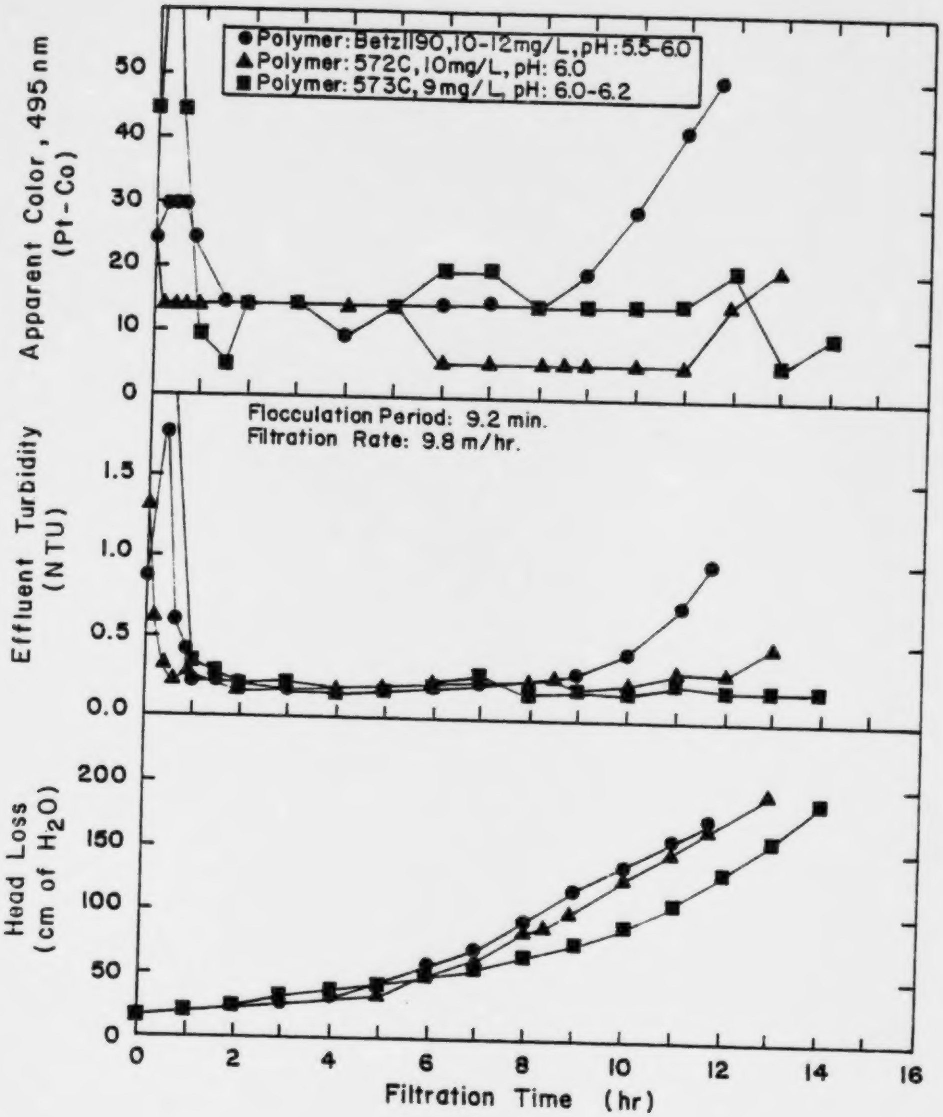

Figure 32. Direct filtration results for three cationic polyelectrolytes (exps. C03P, C05P, C07P).

TABLE 33. CHARGE DOSAGES FOR EXPERIMENTS C03P, C05P, C07P

Exp. No.	Polymer	Dosage* (mg/L)	Solids Content (%)	Actual Polymer Dosage+ (mg/L)	Charge+ (meq/g solids)	Charge Dosage (meq/L)
C03P	1190	12	43.4	5.21	7.98	0.041
C05P	572C	10	50.8	5.08	7.95	0.040
C07P	573C	9	52.6	4.73	8.55	0.040

* Liquid polymer, commercial product basis
+ Dry solids basis

TABLE 34. NET WATER PRODUCTION FOR VARIOUS FILTRATION RATES-IN-LINE OPERATION AT CANTON, N.Y.

Exp. No.	Filt. Rate (m/hr)	Length of Run (hrs.)	Total Water Production (gal)	Backwash Water Used (gal)	Net Water Production (gal)
C10P	4.88	24.0	11,400	2,540	8,860
C06P	9.76	9.5	9,350	1,480	7,870
C11P	14.03	7.4*	10,210	2,170	8,040

* Extrapolated to 200 cm of head loss

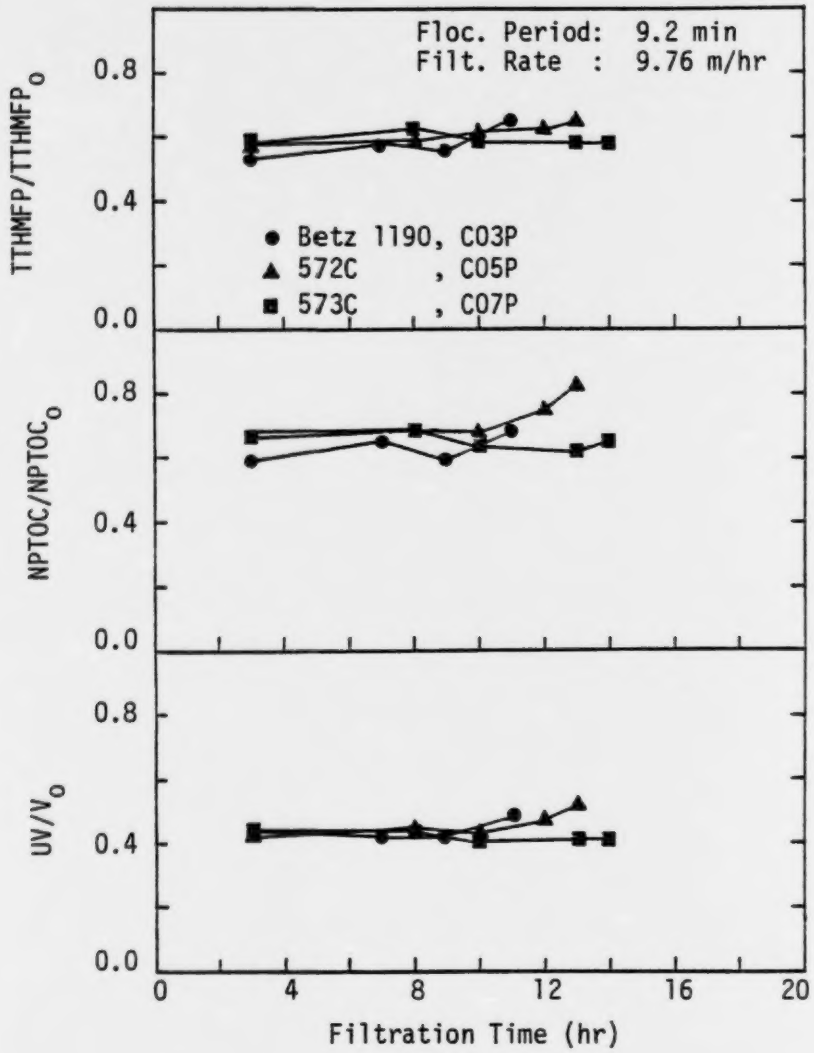

Figure 33. Evaluation of three cationic polyelectrolytes on removals of THM precursors, NPTOC, and UV absorbance.

Polymer dose--Obtaining the proper dosage of coagulant is essential to the proper performance of the filtration process. This has previously been addressed in the Jar Test subsection. Figure 34 shows additional verification of that material. Jar tests were first performed which showed destabilization of color and turbidity at polymer doses of 8-16 mg/L. For the filter run, a dosage of 4 mg/L is an underdose, for dosages ranging from 8-16 mg/L good performance results are obtained, and 25 mg/L is an overdose condition. Note that there is a wide range of polymer dosages, 8 to 16 mg/L, for which the system can be operated to produce excellent quality effluent.

In terms of the dosage of coagulant needed for good performance it is worthwhile to consider its relationship to the quality of the raw water being treated. Two raw water quality parameters, total UV (254 nm) and apparent color, were examined in terms of polymer dosage requirements. Figure 35 plots the "optimum" dosage of Magnifloc 573C used in all pilot plant experiments against the total UV (254 nm) of the raw water. Presented in Figure 36 are similar data using apparent color as the water quality variable. A wide range of total UV (254 nm) (0.15-0.68 cm^{-1}) and apparent color (50-292 Pt-Co units) values were observed during the investigation, yet the results show excellent correlations between the "optimum" dosage and these two parameters. The results indicate that total UV (or apparent color) is a good measure of the humic (organic) content of the Grasse River and thus the polymer dosage requirements. These results are consistent with those of Glaser and Edzwald (1979) and Scheuch and Edzwald (1981) using synthetic humic acid waters. These authors concluded that a stoichiometry existed between the raw water humic acid concentration and the "optimum" destabilization dosage for cationic polyelectrolytes.

From a practical sense, results such as these can be used as an operational tool for monitoring dose requirements in treatment plants. By making fast, relatively simple spectrophotometric measurements of the raw water quality, the polymer dose needed can be predicted.

pH--The effect of pH on direct filtration performance was studied directly in two experiments (C08P, C17P). Figure 37 (Exp. C08P) shows apparent color, turbidity, and head loss data for two pH conditions. At a polymer dosage of 9 mg/L, no significant improvement in performance occurred when the pH was changed from 7.3 (raw water, unadjusted) to pH 6.5.

Figure 38 (Exp. C17P) displays results for four different pH conditions. In this case, the raw water quality contained high levels of color and organic carbon thus requiring a higher dosage of coagulant. From the results it appears that filtration performance improved as the water was acidified from pH 7.3 to 6.4 to 5.5, until turbidity breakthrough occurred at a pH of 5.2. This may be true, but the chosen polymer dosage of 15.3 mg/L at pH 7.3 was most likely a slight overdose as shown by the poor effluent turbidities. Under similar conditions at the "optimum" dosage, turbidity and color measurements would have been considerably lower than the recorded respective values of 0.4 ntu and 25 Pt-Co units. Improved performance at pH 6.4 and 5.5 while holding the polymer dose constant is most likely due to partial destabilization of the humic particles by protons, thus lowering the amount

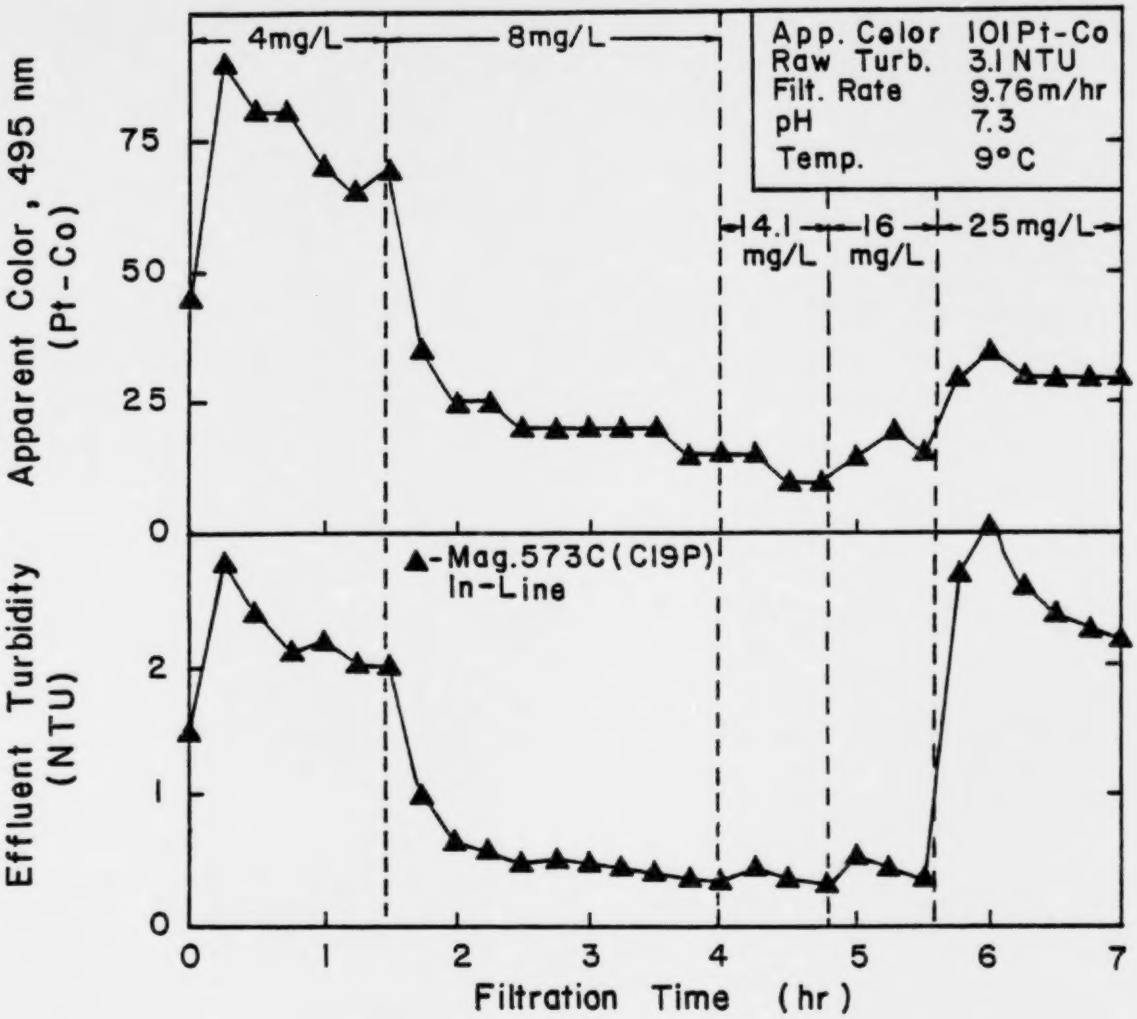

Figure 34. Effect of polymer dose on filter performance (exp. C19P).

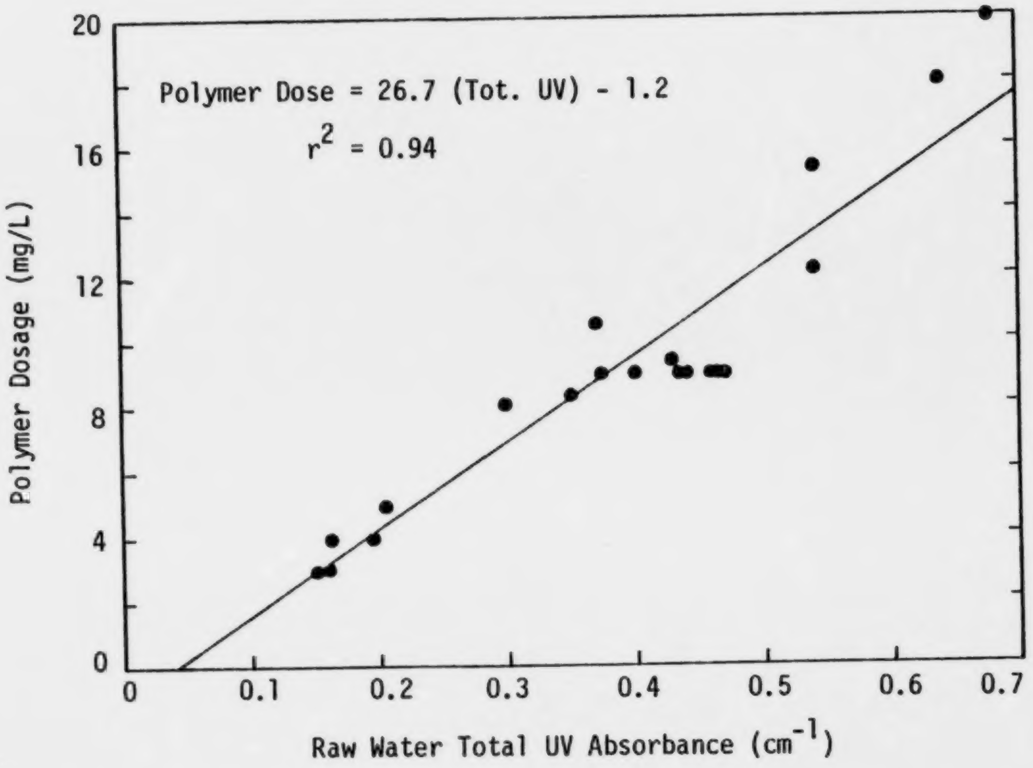

Figure 35. "Optimum" direct filtration polymer dose vs. Grasse River raw water total UV (254 nm).

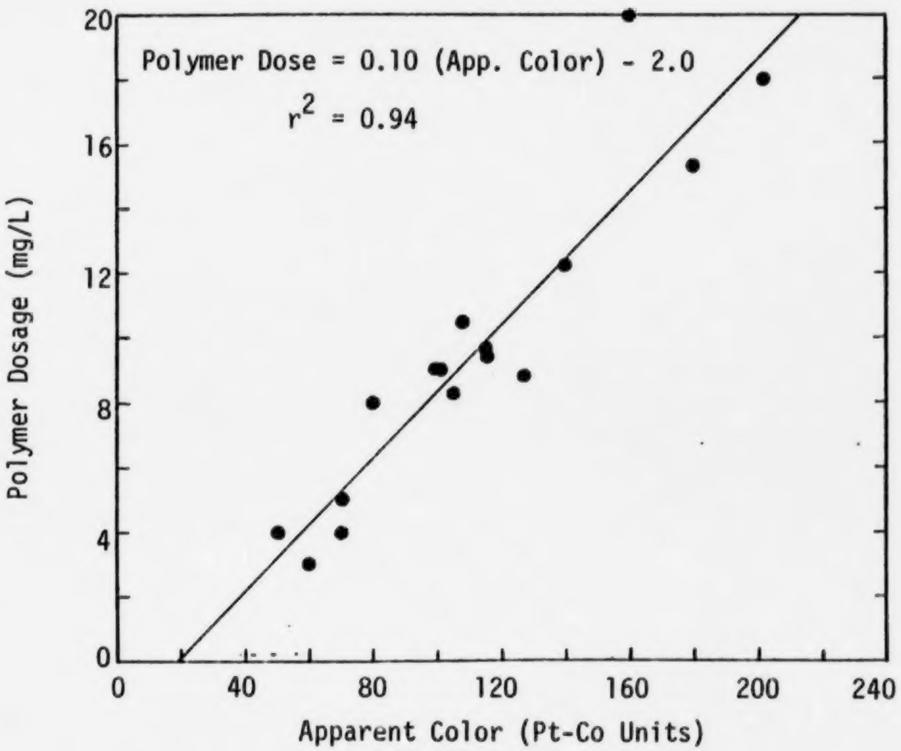

Figure 36. "Optimum" direct filtration polymer dose vs. Grasse River raw water apparent color.

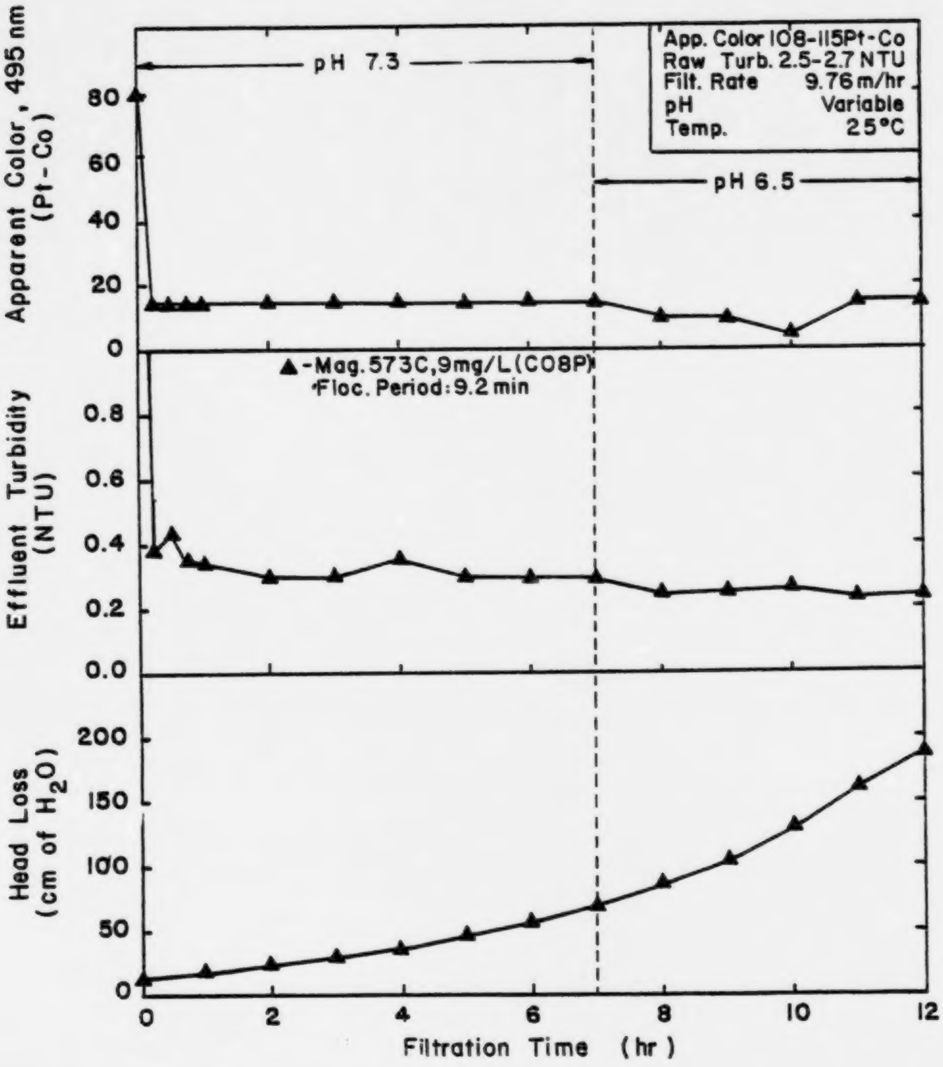

Figure 37. Direct filtration results for two pH conditions (exp. C08P).

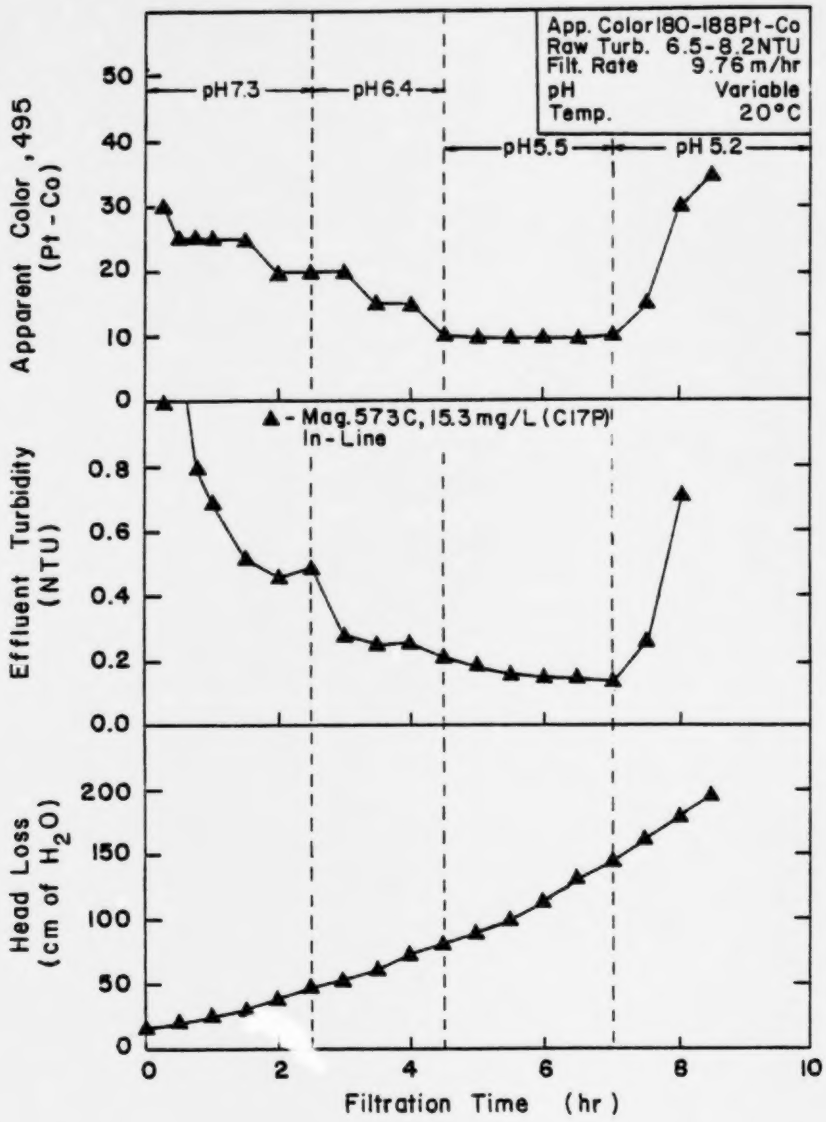

Figure 38. Direct filtration results for exp. C17P at various pH conditions.

of positive charge needed from the polymer for coagulation.

Figure 39 (Exp. C17P) presents the results for organics removals with respect to changes in pH. Here, slightly better performance is shown at the more acidic pH levels. Although not shown, similar results were obtained in experiment C08P. Additional discussion concerning pH effects on organics removals will be presented later.

Filtration rate--Figure 40 shows results of three similar experiments (C10P, C06P, C11P) conducted to examine the effects of filtraiton rate on direct filtration performance. In-line mode of operation was used at filtration rates of 4.88, 9.76, and 14.03 m/hr. Performance relative to removals of turbidity and apparent color was good. As expected, the principal distinction between the three experiments is reflected in the accumulation of head loss with more rapid development at higher filtration rates. Table 34 summarizes the length of each run and net water production data. The net water productions are approximately equal, if one accounts for the inaccuracies associated with determining the actual amount of backwash water used and actually needed.

Removal of organic matter is not significantly affected by filtration rate as shown by the results in Figure 41.

In-line vs. flocculation--In-line direct filtration vs. direct filtration with a flocculation period (flocculation basin) were evaluated at three different filtration rates. The conditions are summarized in Table 35. For a particular flow rate, Tables 32 and Table 12 show that pH, polymer dosage, and raw water quality conditions are approximately constant. This permits, for each pair of experiments, comparison of in-line direct filtration vs. direct filtration with flocculation.

Figures 42, 43, and 44 show direct filtration results for filtration rates of 4.88, 9.76, and ~14 m/hr, respectively. The results show excellent performance for turbidity and color with no significant difference between the in-line vs. flocculation modes.

Figure 45 shows results for the removals TTHMFP, NPTOC, and UV (254 nm) at a 9.76 m/hr filtration rate. Results indicate no major difference in performance with respect to the use or absence of flocculation. Similar results were obtained at the other filtration rates.

In terms of head loss considerations there are significant differences. Results in Figures 42, 43, and 44 and summarized in Table 35 indicate that by using a flocculation period, longer filter runs are achieved.

To understand the effects of flocculation with respect to filtration, head loss distribution through the filter bed was investigated. Figures 46 and 47 present these distributions with respect to filtration mode at a filtration rate of 9.76 m/hr. Figure 46 (in-line) shows that initially the distribution of head loss through the bed is spread fairly uniformly over the depth of the filter bed. With time, however, the top portion of the bed

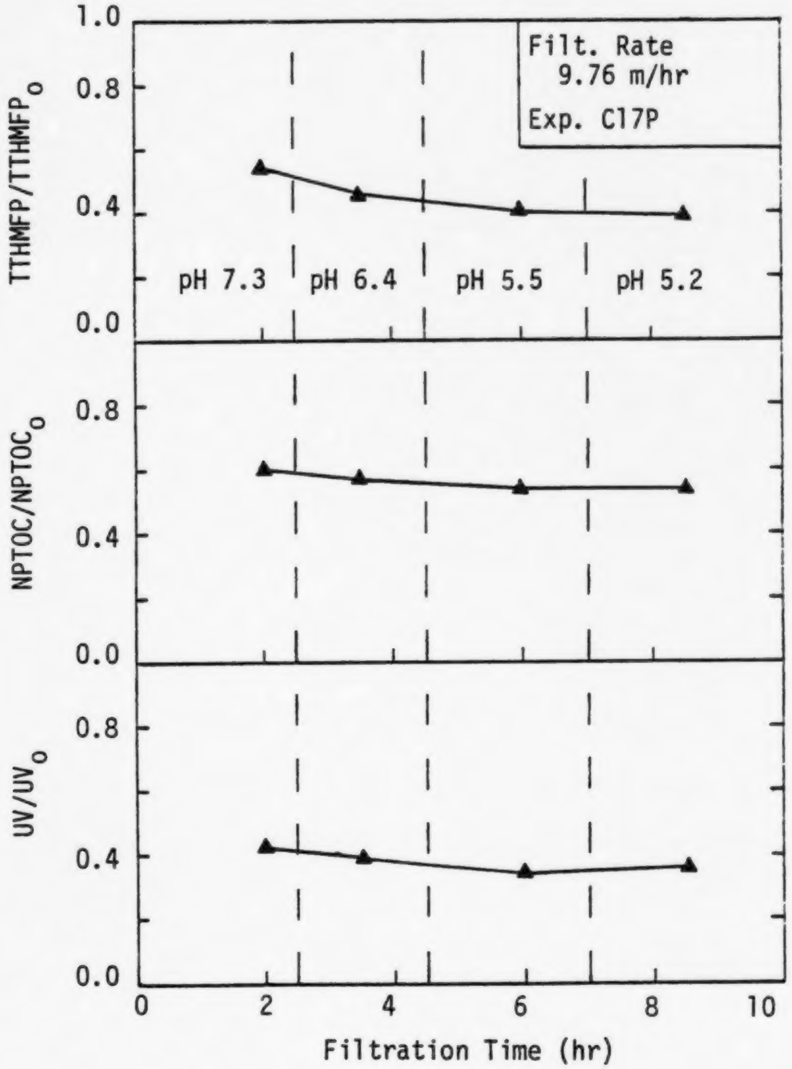

Figure 39. Effects of pH on removals of THM precursors, NPTOC, and UV absorbance (exp. C17P).

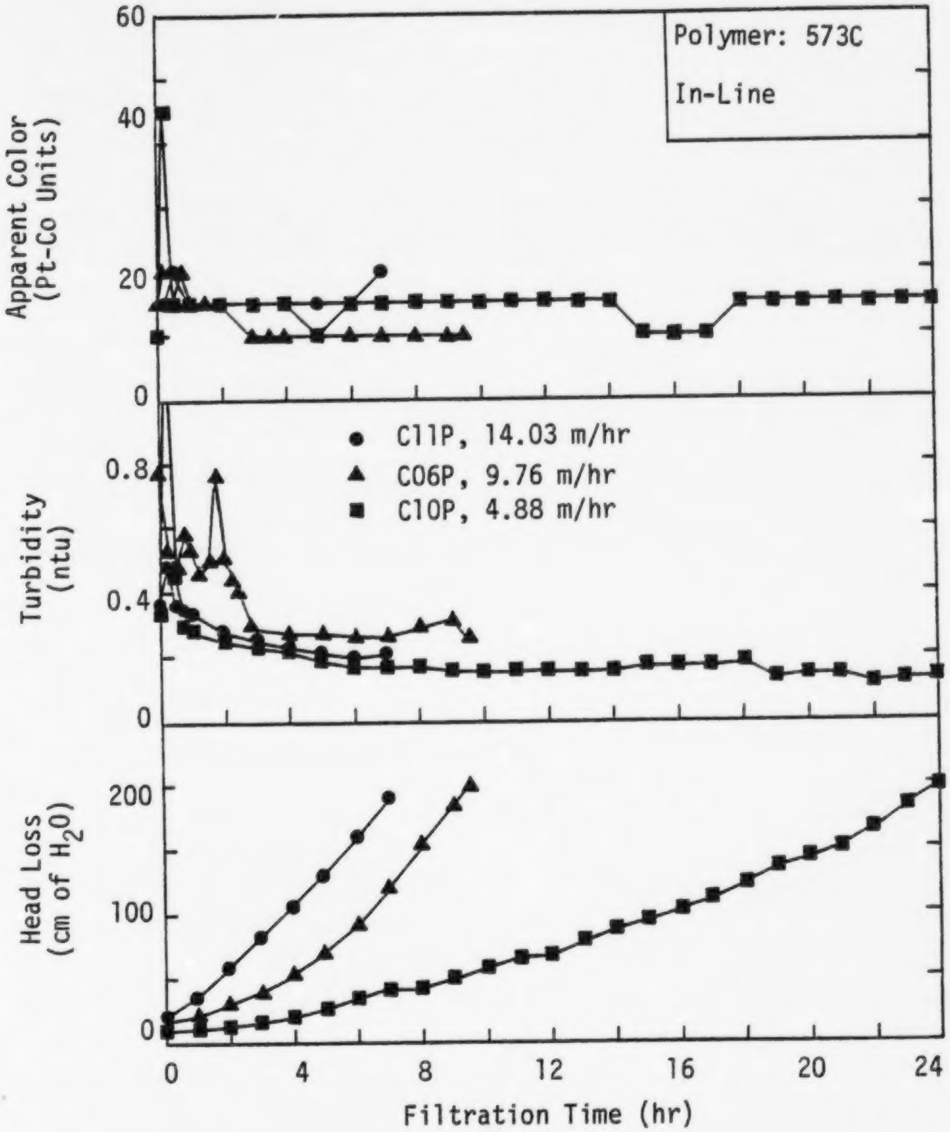

Figure 40. Effect of filtration rate on performance in the in-line direct filtration mode.

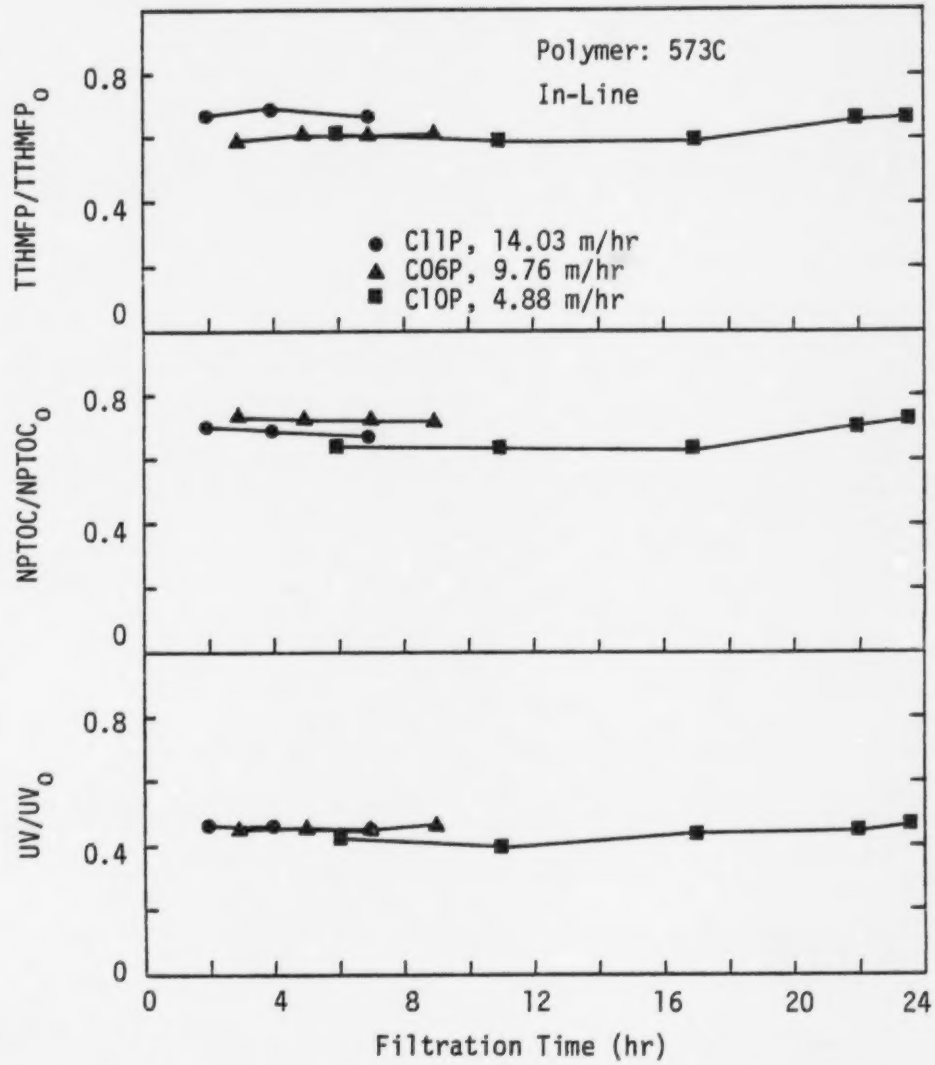

Figure 41. Effect of filtration rate on removals of THM precursors, NPTOC, and UV absorbance (In-line filtration).

TABLE 35. SUMMARY OF FILTER EXPERIMENTS COMPARING IN-LINE VS. FLOCCULATION

Exp. No.	Filt. Rate (m/hr)	Floc. Tank Detention Period (min)	Total Detention Time* (min)	Filter Run Length (hr)	Head Loss in Top 19 cm+ (%)
C10P	4.88	0	14.3	24.0	84
C09P	4.88	18.4	32.7	24.0‡	NA
C06P	9.76	0	7.2	9.5	74
C07P	9.76	9.2	16.4	14.0	49
C11P	14.03	0	4.8	7.0	51
C12P	14.6	6.1	10.9	8.5	41

* - Detention time from point of polymer addition to the filter media surface

+ - Percent of total head loss across bed at termination

‡ - Run terminated after 100 cm of head loss; all other runs at 200 cm

NA - not applicable

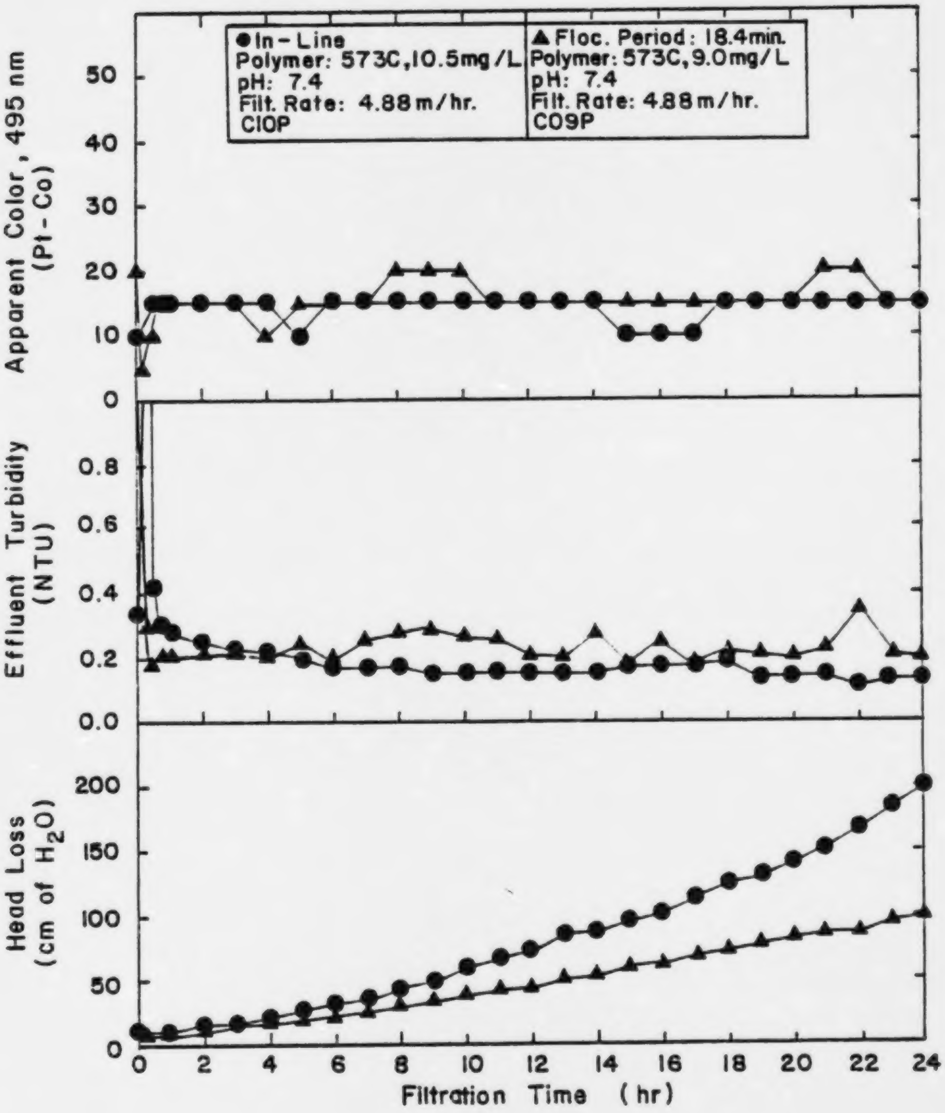

Figure 42. Comparison of in-line filtration vs. flocculation at rate of 4.88 m/hr.

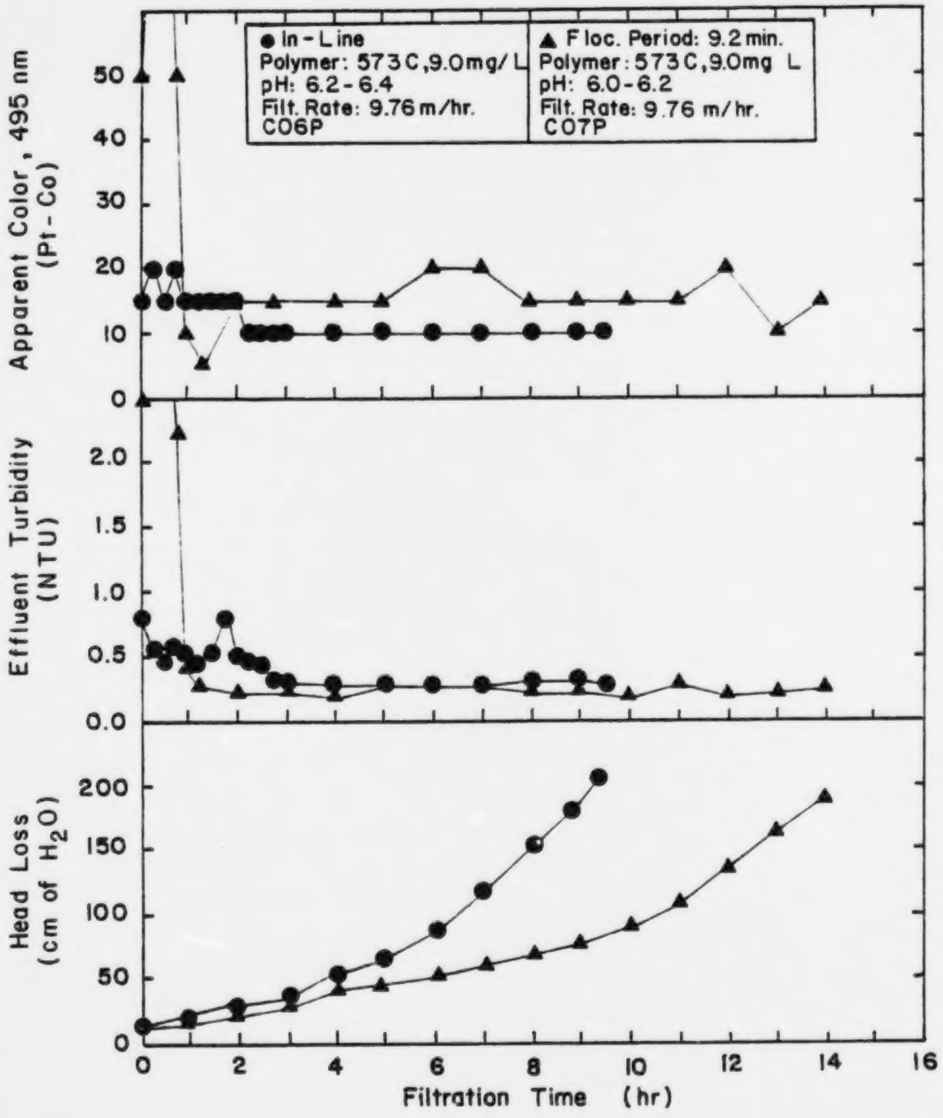

Figure 43. Comparison of in-line filtration vs flocculation at rate of 9.76 m/hr.

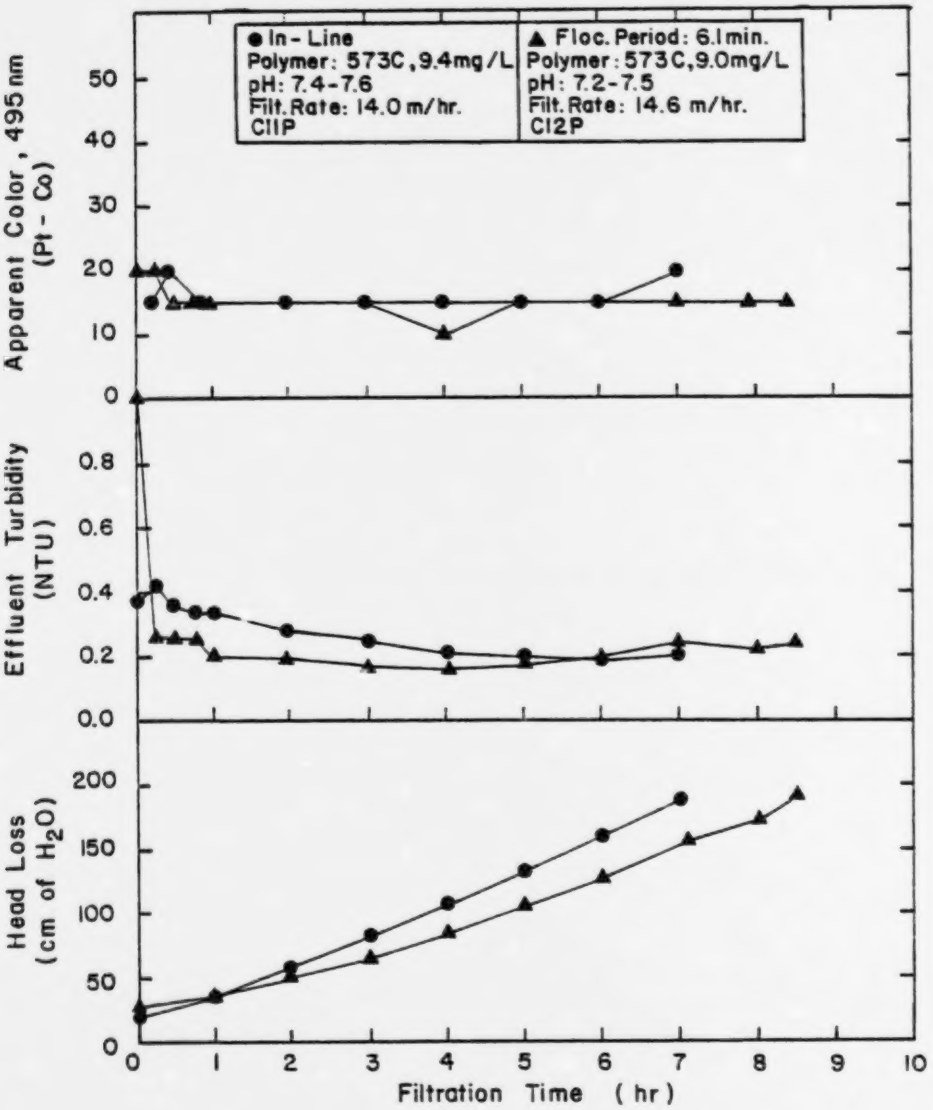

Figure 44. Comparison of in-line filtration vs. flocculation at rate of approximately 14 m/hr.

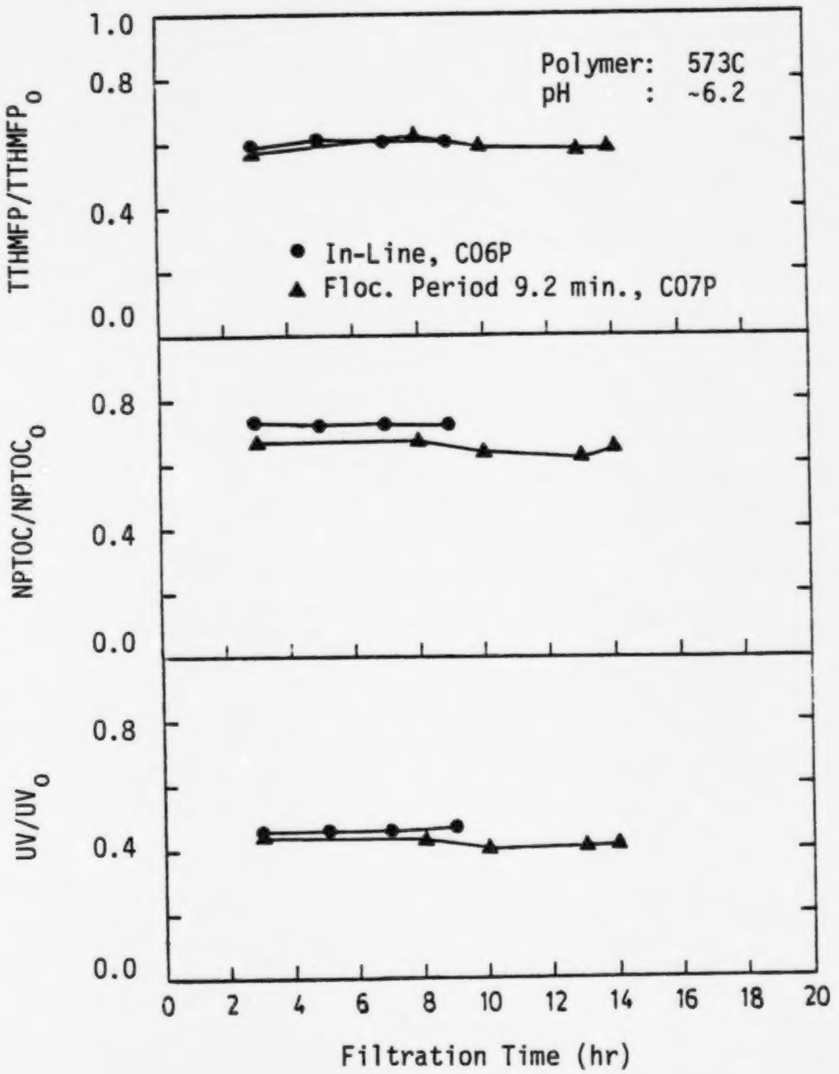

Figure 45. Effects of in-line filtration vs. flocculation on removals of THM precursors, NPTOC and UV absorbance for filtration rate of 9.76 m/hr.

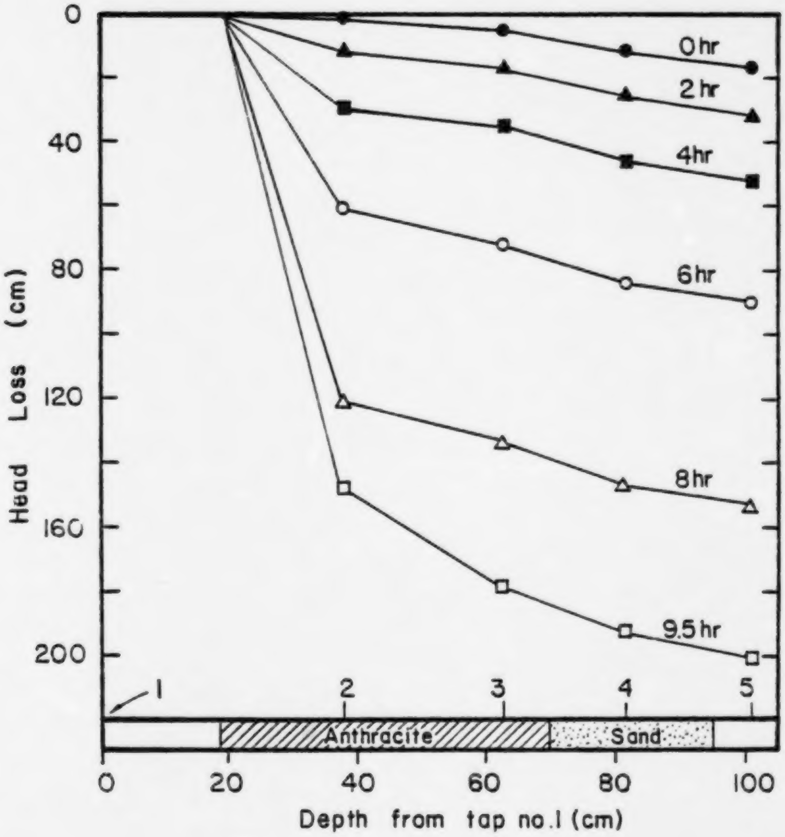

Figure 46. Head loss distributions as a function of filtration time for in-line filtration at rate of 9.76 m/hr.

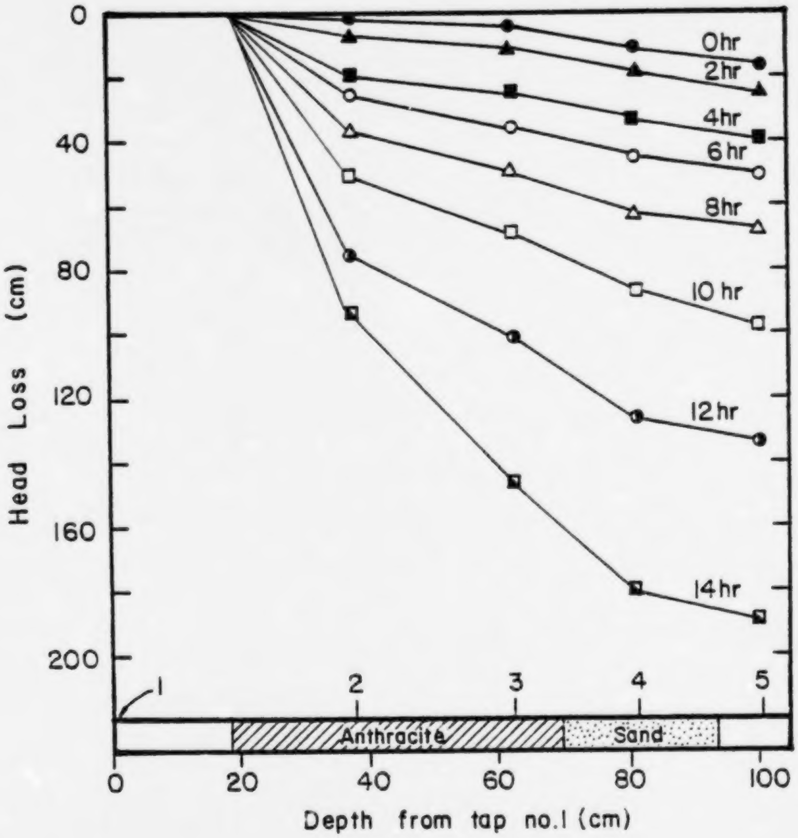

Figure 47. Head loss distributions as a function of filtration time for filtration with flocculation at rate of 9.76 m/hr.

quickly accumulates the majority of the head loss. At 9.5 hours, the termination time, approximately 74 percent of the head loss occurred in the top 19 cm of the anthracite layer. Most of the particles are therefore being removed in the top of the bed.

By contrast, Figure 47 shows that by using a relatively small flocculation period, a longer filter run length time was attained - 14 hr vs. 9.5 hr. Also a greater portion of the bed was utilized throughout the entire 14 hour run. It is worthy to note, however, that the top portion of the bed (19 cm) was still responsible for nearly half of the total head loss, 49 percent.

Head loss distributions for the various filtration rates are shown in Figure 48 for in-line filtration and in Figure 49 for flocculation. These plots show the distributions near termination of the runs - i.e., at approximately 2 m of total head loss. The data in Figure 48 show that with increasing filtration rate more of the head loss occurs deeper in the bed, as expected. However, in all cases most of the head loss occurs in the top 19 cm of the anthracite. With flocculation (Figure 49) there is a more uniform distribution of head loss, but again 40-50 percent of the total head loss occurs in the top of the bed. In Figure 49 the 4.76 m/hr filtration rate is not plotted since only 1 m of head loss occurred after 24 hrs (see Figure 42). However most of the head loss occurred in the top of the bed, 83.4 cm of a total of 100 cm head loss occurred in the top 19 cm.

We can assume that when treating water during the summer with in-line treatment the humic particles being applied to the filter are in the submicron diameter size range. When flocculation is applied, particles are aggregated to larger sizes, say 1 to 10 or even 20 μm for the 4.88 m/hr filtration rate. These conditions are used to explain the head loss results. As presented in the Literature Review, the head loss developed within a filter bed varies inversely with the size of the particles being applied. Therefore the use of flocculation increases filter run length by increasing the size of the particles.

Once a filter run has begun the majority of particle attachment in a filter is to those particles which have been previously retained, usually at the top of the filter, regardless of size. This is shown in Table 35 by the percent of head loss accumulated in the top 19 cm of the bed. In all cases it is greater than 40 percent. Figures 46 and 47 also show that as filtration time proceeds, most of the head loss buildup is in the top of the bed.

Particles being applied to the filter in the in-line mode (sub-mircon size) would have a high transport efficiency (single collector efficiency) - see Figure 26. This is reflected in the high percentage of accumulation in the top of the bed for those experiments using in-line treatment. For those experiments in which flocculation was used, transport efficiencies would decrease due to increase in size of some particles to the micron size range (minimum in η_T, Figure 26). These particles would travel deeper into the bed before being removed thus distributing the head loss more evenly.

Temperature--Figure 50 presents the results of a filter run (Exp. C22P)

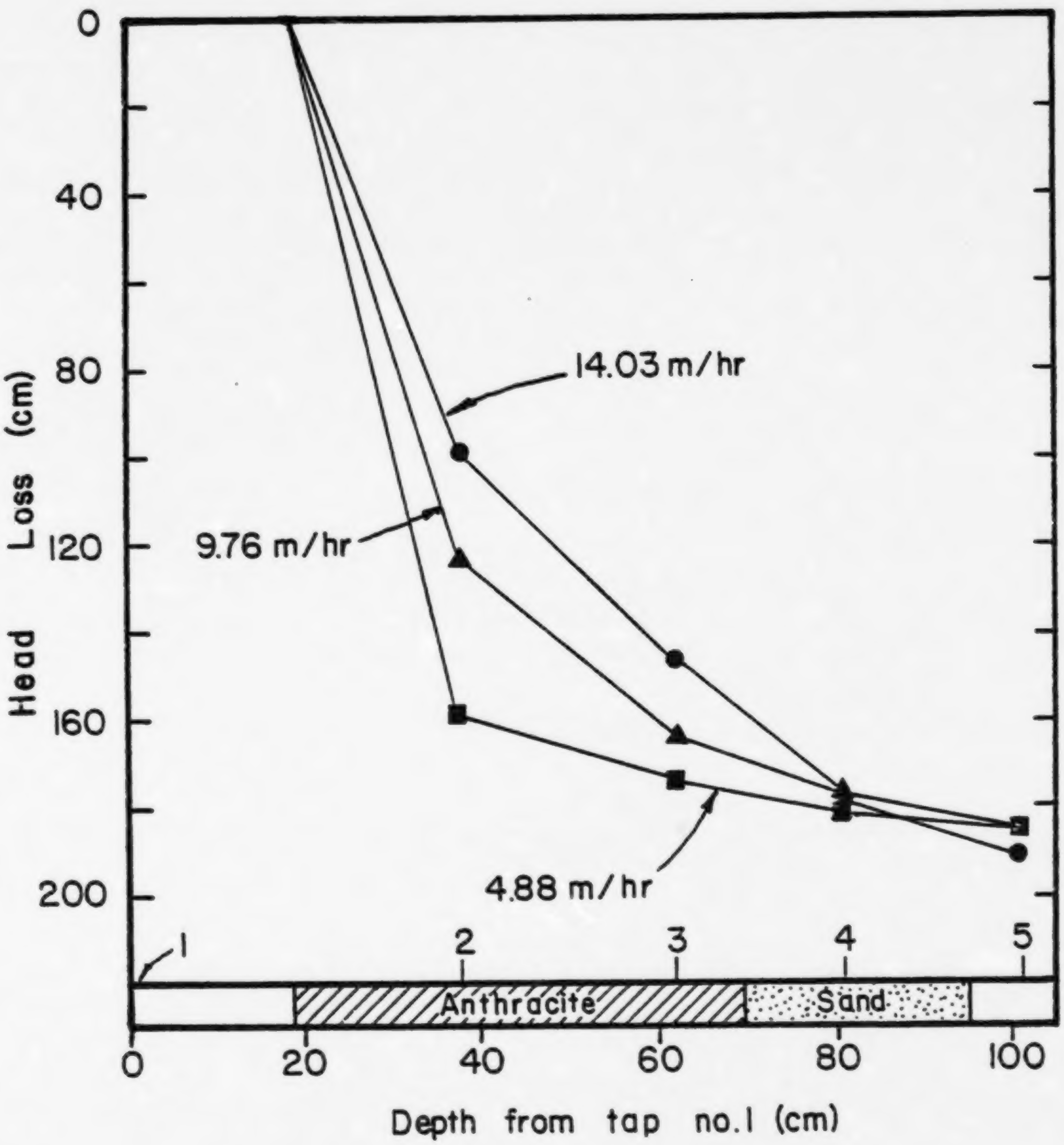

Figure 48. Effect of filtration rate on head loss distribution for in-line filtration.

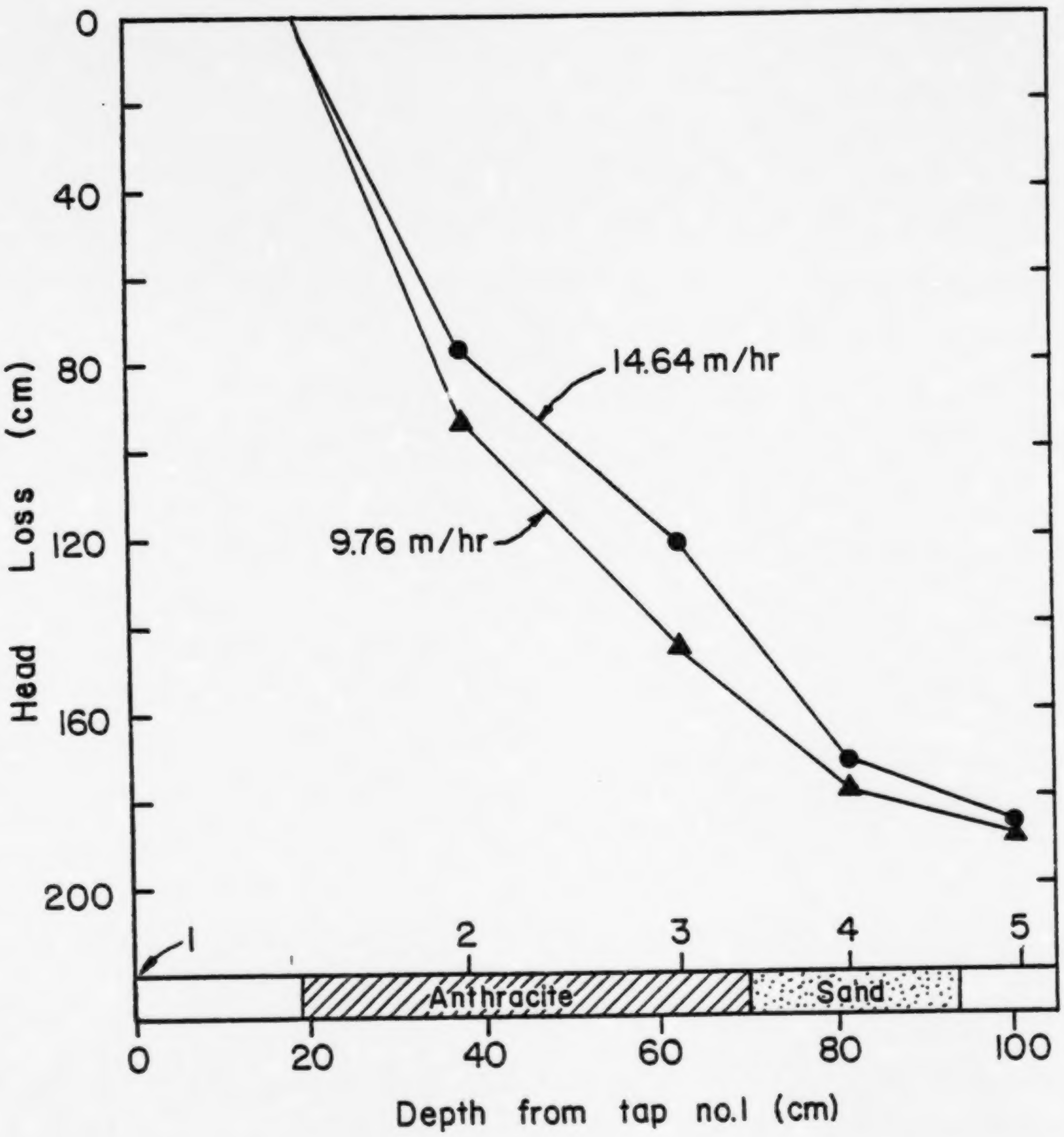

Figure 49. Effect of filtration rate on head loss distribution for filtration with flocculation.

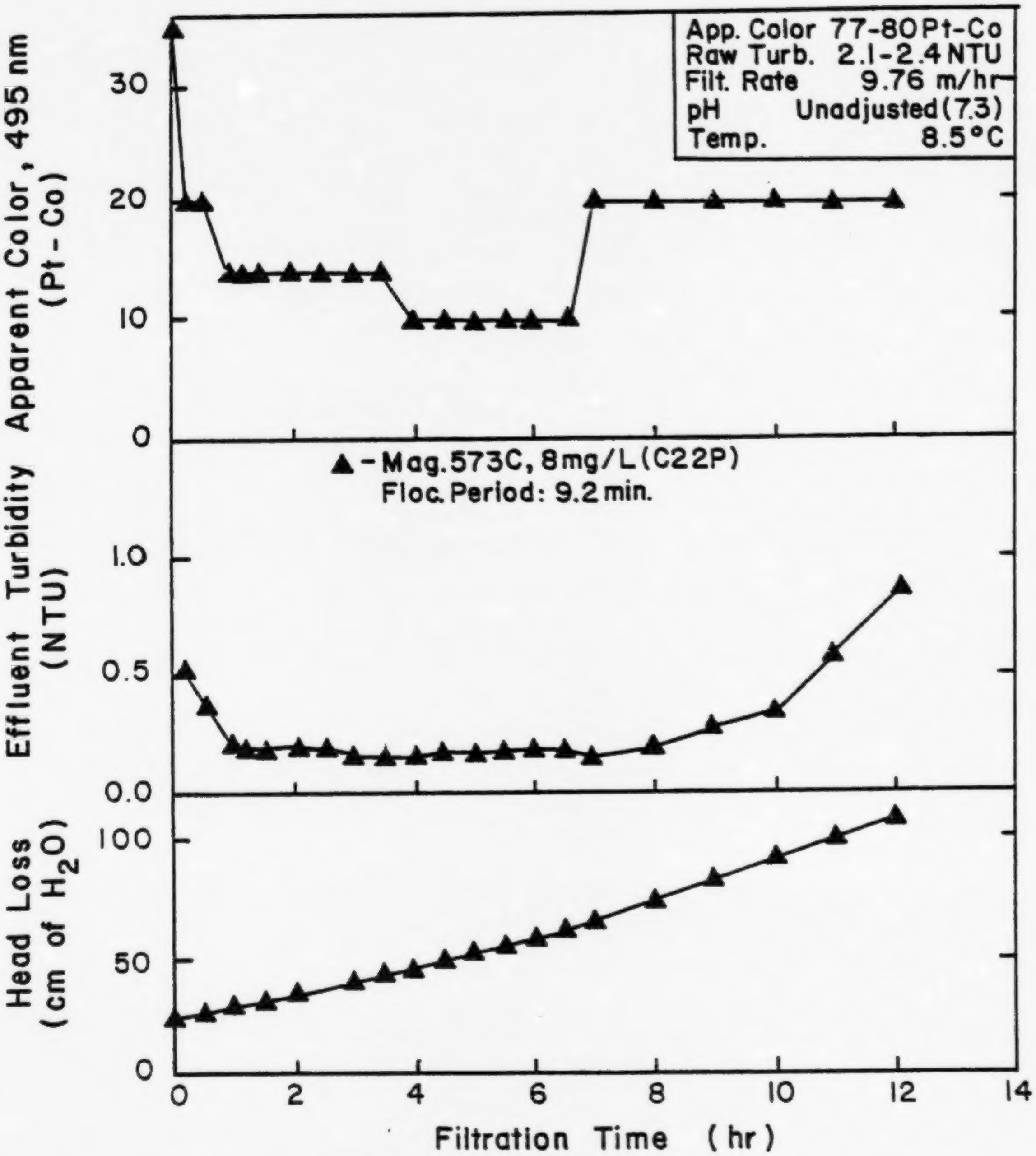

Figure 50. Filter results for exp. C22P
(Fall period, water temp. 8.5°C).

conducted during the fall at a cold water temperature of 8.5°C. The raw water quality included a turbidity of approximately 2.4 ntu and apparent color of 80 Pt-Co units. Filtration operating conditions were no pH adjustment, a filtration rate of 9.76 m/hr, a 9.2 minute flocculation time, and Magnifloc 573C as the coagulant. Unlike previous experiments conducted during the warm summer months, turbidity breakthrough occurred before a terminal head loss was reached. After 12 hours of filtration time, turbidity performance had deteriorated to approximately 1 ntu with only 110.6 cm of head loss.

Figure 51 compares the distribution of head loss through the filter bed for this filter run at 8.5°C with a run at similar conditions but at a temperature of 23°C. At the lower temperature the head loss did not build up in the upper portion of the bed.

The premature turbidity breakthrough and the lack of accumulation of head loss in the top of the bed verifies that temperature plays a role in flocculation and filtration processes. At a temperature of 23°C, small particles (~0.01 μm) can aggregate rapidly to larger particles (about 1 to 20 μm). At lower temperatures such as 8.5°C, kinetics of particle aggregation are much slower. Therefore, transport efficiencies at this temperature may be such as to produce particles consistently within the minimum size range for filter collector efficiency (2-3 μm). Therefore, as shown in Figure 51, particles penetrated deeper into the bed before removal occurred, until after about 10 hours turbidity breakthrough occurred (Figure 50). This suggests that a longer flocculation period may be needed during periods of cold weather to allow particles to aggregate to a greater size. If total head loss accumulation is not large, no flocculation (in-line) may be better than a short flocculation period - i.e., the particles will remain sub-micron in size without flocculation, where particle transport efficiency is good.

Performance Using Alum--

Although the primary objective of the study was to investigate the use of cationic polyelectrolytes as primary coagulants in direct filtration, alum was used in a few experiments - one using the Waterboy (C23P) and two using the small scale system (C24A, C25A).

First, the small scale results are presented. Figure 52 shows effluent turbidity and apparent color along with head loss accumulation against filtration time for an in-line experiment using 15 mg/L alum. Raw water conditions included an apparent color of 73 Pt-Co units, a turbidity of 3.9 ntu, and a temperature of 6°C. The pH of the raw water was adjusted to 5.5. A filtration rate of 4.88 m/hr was employed. Results indicate excellent turbidity and color removal with effluent values averaging approximately 0.2 ntu and 10 Pt-Co units, respectively. Terminal head loss (186 cm) was reached after 10 hrs and coincided with deterioration and breakthrough of effluent turbidity.

Figure 53 presents results from a similar experiment with a 48 minute flocculation period. Raw water quality was slightly different at 58 Pt-Co units of color, a turbidity of 3.2 ntu, and a temperature of 10°C. Excellent results were obtained. Effluent color was undetectable and effluent

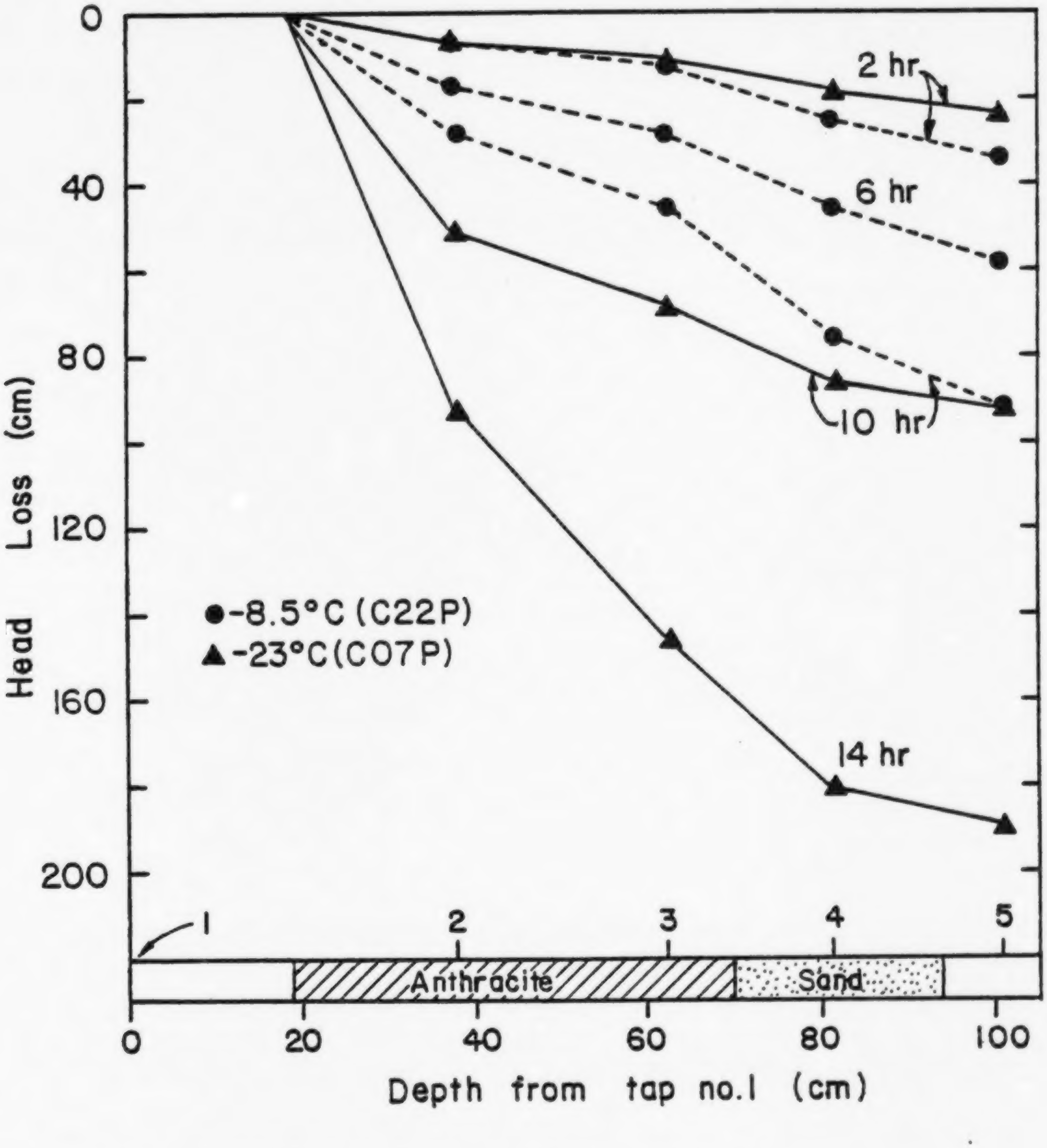

Figure 51. Comparison of head loss distributions for exp. C07P at 23°C and exp. C22P at 8.5°C.

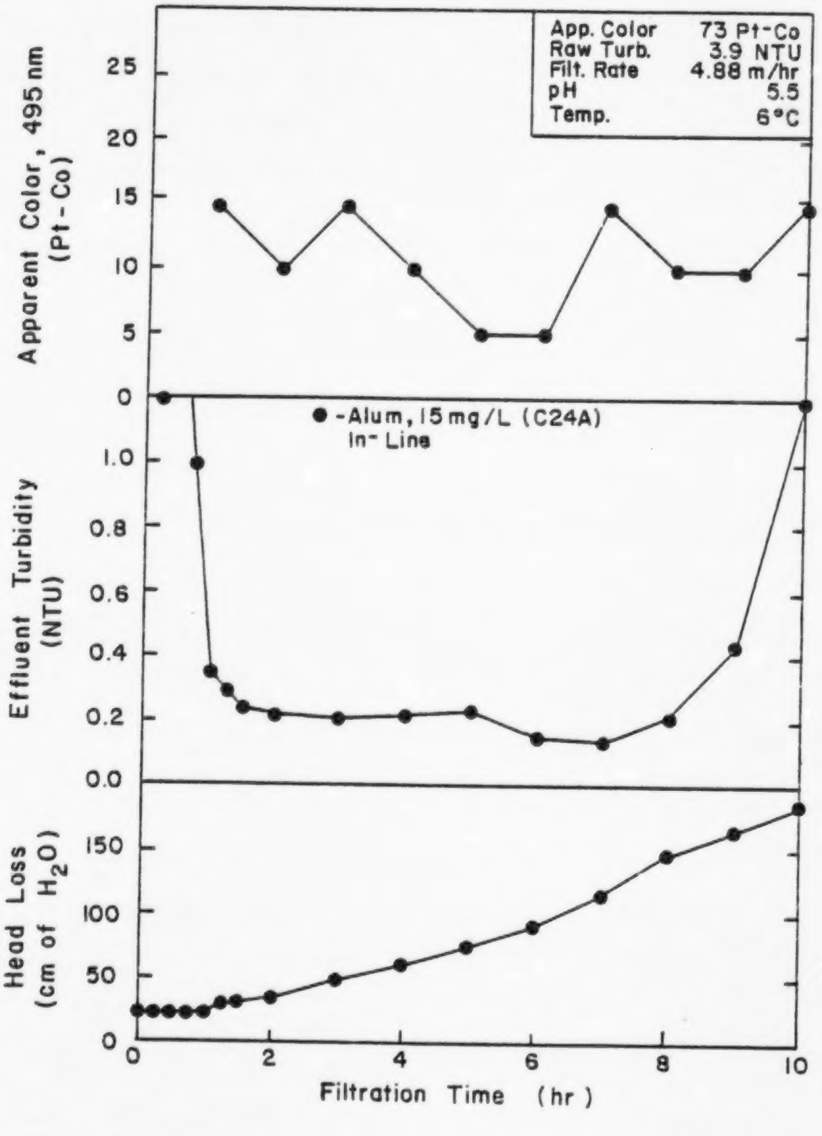

Figure 52. Small scale in-line filter results using alum (exp. C24A).

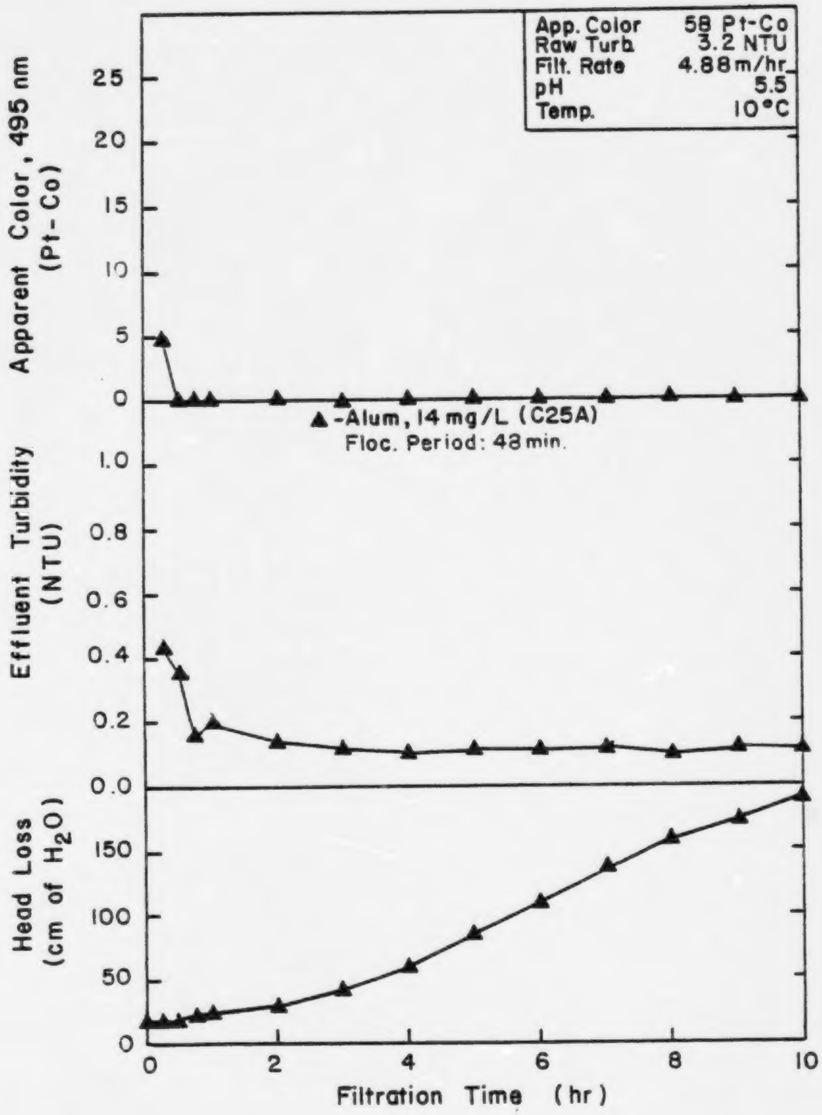

Figure 53. Small scale results for filtration with flocculation using alum (exp. C25A).

turbidities averaged 0.12 ntu. The length of the filter run was 10 hrs, the same as without flocculation, however, no sign of performance deterioration was in evidence.

A final example of performance using alum is shown in Figure 54. A higher dose of alum (20 mg/L) was needed due to a higher raw water color of 90 Pt-Co units. Turbidity and color breakthrough occurred after about 7 hours with little head loss development indicating poor particle removal. In this case the alum dose was not at the proper value, or there was need for addition of a filter aid.

In general, alum dosages are relatively high due to the high color and organic content of the Grasse River. Also, various operational difficulties arose when using alum. The success of performance is highly dependent upon proper pH control, which was sometimes difficult to attain while at the same time trying to keep the alum dose as low as possible to avoid excessive production of aluminum hydroxide particles.

Summary of the Removals of Organic Matter--

The organic matter in the raw water and the filter effluent was measured by four parameters: apparent color, NPTOC, total UV (254 nm) and 7-day TTHMFP. Tables 36 and 37 contain a summary of the percent removals of the indicating parameters for direct filtration using polymers and alum as coagulants, respectively. Note that Table 37 includes experimental results from the Initial Phase studies. Reference should be made to Table 12 for raw water quality conditions.

Excluding those experiments with dosage changes, results in Table 36 indicate removals in the following percent ranges: 84-95 for apparent color, 54-66 for total UV, 25-47 for NPTOC, and 34-60 for TTHMFP, with the highest removals occurring at the lowest pH conditions. Experiments C08P, C17P, and C18P show a definite trend toward greater removals at more acidic pH conditions.

Two experiments (C19P and C21A) were conducted at various polymer dosages. Results indicate that at polymer underdose conditions, removals are poor. At the optimum dosage taken from jar test results, removals fall within the expected ranges outlined above. At polymer overdose conditions, removals of organic matter improve. Polymer overdosing for filter performance is based on turbidity and color - see Figures 28b and 34. It is not clear why removals of UV, NPTOC, and TTHMFP improved.

Compared to direct filtration with polymers, results in Table 37 indicate that, in general, greater removals of organic matter are achieved with alum. Ranges of percent removals are as follows: 85-100 for apparent color, 68-80 for total UV, 46-75 for NPTOC, and 50-74 for TTHMFP.

These performance results will be discussed in Section 8.

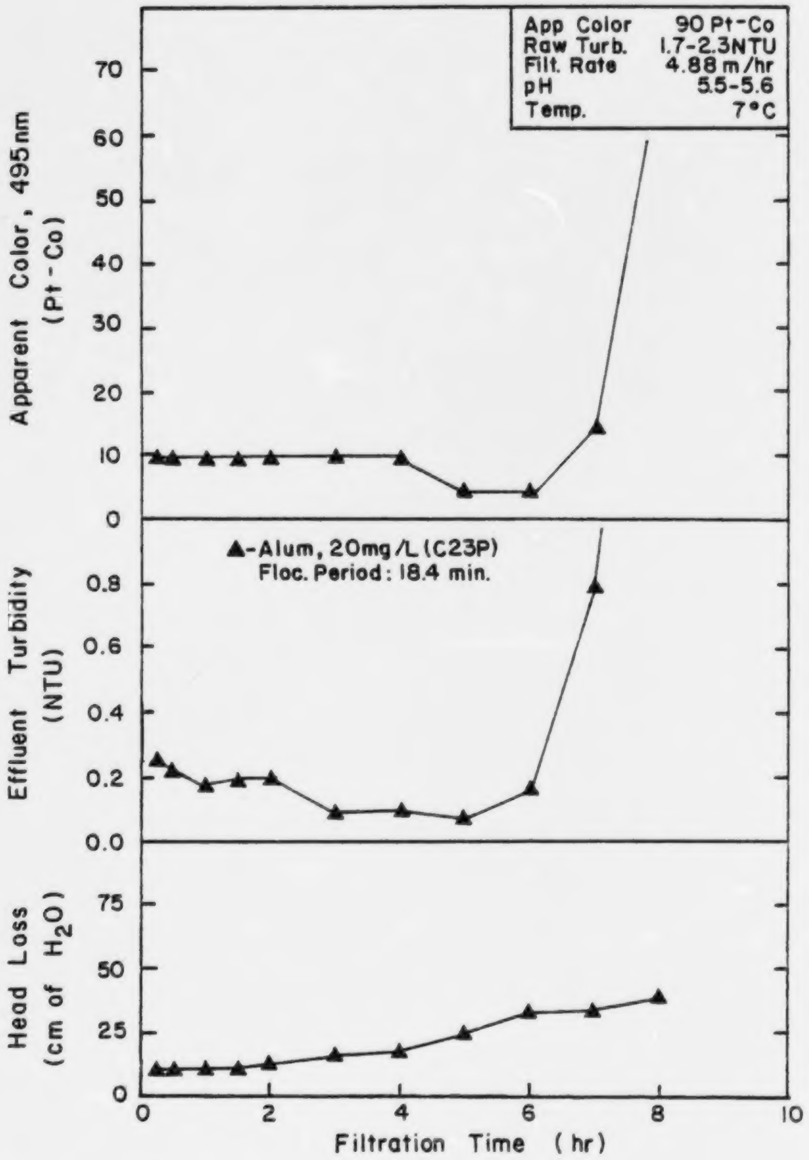

Figure 54. Waterboy filter results using alum (exp. C23P).

TABLE 36. SUMMARY OF ORGANICS REMOVALS USING POLYMERS (CANTON, N.Y.)

Exp. No.	Polymer	Dosage (mg/L)	Filt. Rate (m/hr)	Filt. Mode	pH	Percent Removal App. Color	Total UV	NPTOC	TTHMFP
C01P	1190	10	9.76	I-L	7.2	85	55	33	34
C02P	1190	13	9.76	I-L	6.0	92	56	25	34
C03P	1190	12	9.76	Floc	5.5-5.9	90	58	39	45
C04P	572C	12	9.76	I-L	6.1	88	56	34	42
C05P	572C	10	9.76	Floc	6.0	92	55	31	40
C06P	573C	9	9.76	I-L	6.2-6.4	91	55	28	39
C07P	573C	9	9.76	Floc	6.0-6.2	89	58	35	41
C08P	573C	9	9.76	Floc	7.3	87	54	30	34
					6.5	88	62	36	42
C09P	573C	9	4.88	Floc	7.5	85	56	32	37
C10P	573C	10.5	4.88	I-L	7.5	86	58	33	38
C11P	573C	9.4	14.03	I-L	7.5	84	54	32	32
C12P	573C	9	14.64	Floc	7.3	85	59	37	43
C17P	573C	15.3	9.76	I-L	7.3	88	57	40	44
					6.4	93	61	43	54
					5.5	95	66	45	60
					5.2	80	64	45	60
C18P	573C	20	9.76	I-L	5.7	91	63	45	46
					5.3	91	66	47	48
C19P	573C	4 u	9.76	I-L	7.3	29	9	-1	3
		8 j				80	44	33	28
		25 o				72	72	57	64
C22P	573C	8	9.76	Floc	7.2	81	52	34	39
C21A	573C	2 u	4.88	I-L	6.7	49	3	12	10
		4 j				86	46	37	40
		8				80	69	31	67
		12 o				82	77	61	79
C23A	573C	5	4.88	Floc	7.0	87	63	30	36

u - underdose
j - jar test optimum
o - overdose

Floc - Floc. Period
I-L - In-Line

TABLE 37. SUMMARY OF ORGANICS REMOVALS USING ALUM (CANTON, N.Y.)

Exp. No.	Coagulant	Dosage (mg/L)	Filt. Rate (m/hr)	Filt. Mode	pH	Percent Removal App. Color	UV	NPTOC	TTHMFP
C23P	Alum	20	4.88	Floc	5.5-5.6	91	80	75	74
C24A	Alum	15	4.88	I-L	5.5-5.7	85	73	46	61
C25A	Alum	14	4.88	Floc	5.5	100	79	63	62
C15A	Alum	15	4.88	I-L	6.0	92	78	57	57*
					5.3-5.4	92	78	56	59*
C17A	Alum	10	4.88	Floc	5.2-5.5	100	68	48	50*
C20B	Alum	12.5	4.88	I-L	5.4-5.6	88	74	57	50*

* - 5-day TTHMFP

Floc - Floc. Period

I-L - In-line

DIRECT FILTRATION PILOT PLANT EXPERIMENTS AT ONEIDA

This section is organized by first presenting small scale pilot results and then the large scale (Waterboy) results.

Small Scale Direct Filtration Experiments

Numerous small scale experiments were conducted between July 1980 and June 1981. These experiments were of a preliminary nature designed to gain experience in operating the small scale pilot plant. Based on that experience, 11 experiments were performed over an eight month period from July 1981 to March 1982. A summary of the operating conditions for the eleven experiments is presented in Table 38. Raw water quality data are in Table 14. Polymer dosages presented in Table 38 and in the following figures are on a commerical product basis. All small scale experiments were conducted at a filtration rate of 4.88 m/hr (2 gpm/ft^2).

These small scale runs served many purposes. First, comparisons of alum, cationic polyelectrolytes, and alum-polymer combinations were made. Second, experimental results were evaluated with respect to removal of THM precursors and other organic constituents. Third, the effects of various physical and chemical variables on filtration performance were evaluated. Finally, these small scale experiments were used to design the large scale Waterboy experiments.

Jar tests were used to select the required coagulant dosage for direct filtration, relying primarily on true color measurements of supernatant samples to indicate the required dosage. In this subsection, filtration performance in terms of the traditional parameters of apparent color, turbidity, and head loss development will be discussed. Organics removal for both the small and large scale pilot plants is discussed jointly in a later subsection.

Cationic Polymers--

Figure 55 presents the results of three filter experiments which were conducted to compare three different cationic polymers. These experiments were conducted during the fall overturn period for the Glenmore Reservoir. Raw water characteristics included apparent color of 63-75 Pt-Co units, turbidity of 0.75-0.90 ntu, a total UV (254 nm) absorbance of 0.17 cm^{-1}, and a temperature of 13°-14°C during the experiments. The temperature presented for small scale filter experiments often will not coincide with raw water temperatures presented in Table 14 due to warming of the water during storage prior to filter experiments. All three experiments were conducted at pH 5.9.

During the initial stages of experiment 17A, several changes in the Magnifloc 572C dosage were made until the required dosage of 8 mg/L was found. All three polymers worked well (once the correct dosage was found for experiment 17A), with effluent turbidities of 0.1-0.3 ntu and effluent apparent color of 7-25 Pt-Co units. Experiments 17B, using 6 mg/L of Magnifloc 573C, and 18A, using 6 mg/L of Betz 1190, outperformed Magnifloc 572C with respect to color and turbidity removals. Both Magnifloc 573C and Betz 1190 achieved effluent turbidities of approximately 0.1 ntu after filter

TABLE 38. SUMMARY OF SMALL SCALE FILTER EXPERIMENTS (ONEIDA, N.Y.)

Exp. No.	Date	Coagulant	Dosage (mg/L)	pH	Flow (mL/min)	Filt. Rate (m/hr)	Floc. Period (min)	Temp (°C)	Comment
15B	7/20/81	Alum	10-12	5.5	126.5	4.88	-	20	
16B	7/21/81	Alum	10-11	5.5	126.5	4.88	-	20	1 mg/L of 573C added to raw water reservoir
17A	10/22/81	572C	5-8	5.9	126.5	4.88	-	13	
17B	10/22/81	573C	6	5.9	126.5	4.88	-	13	
18A	10/23/81	1190	6	5.9	126.5	4.88	-	14	
18B	10/23/81	Alum	14-15	5.6	126.5	4.88	-	14	
19A	1/5/82	Alum	12	5.7	126.5	4.88	-	10	
19B	1/5/82	Alum	12	5.7	126.5	4.88	-	13	24 min. contact time for alum prior to addition of 0.1 mg/L of 985N
20A	1/5/82	573C	2.5	5.8	126.5	4.88	-	13	
21A	3/4/82	Alum	10	5.8-6.0	126.5	4.88	48	7	
21B	3/4/82	Alum	10	5.7-5.9	126.5	4.88	48	11	0.1 mg/L of 985N applied on top of filter

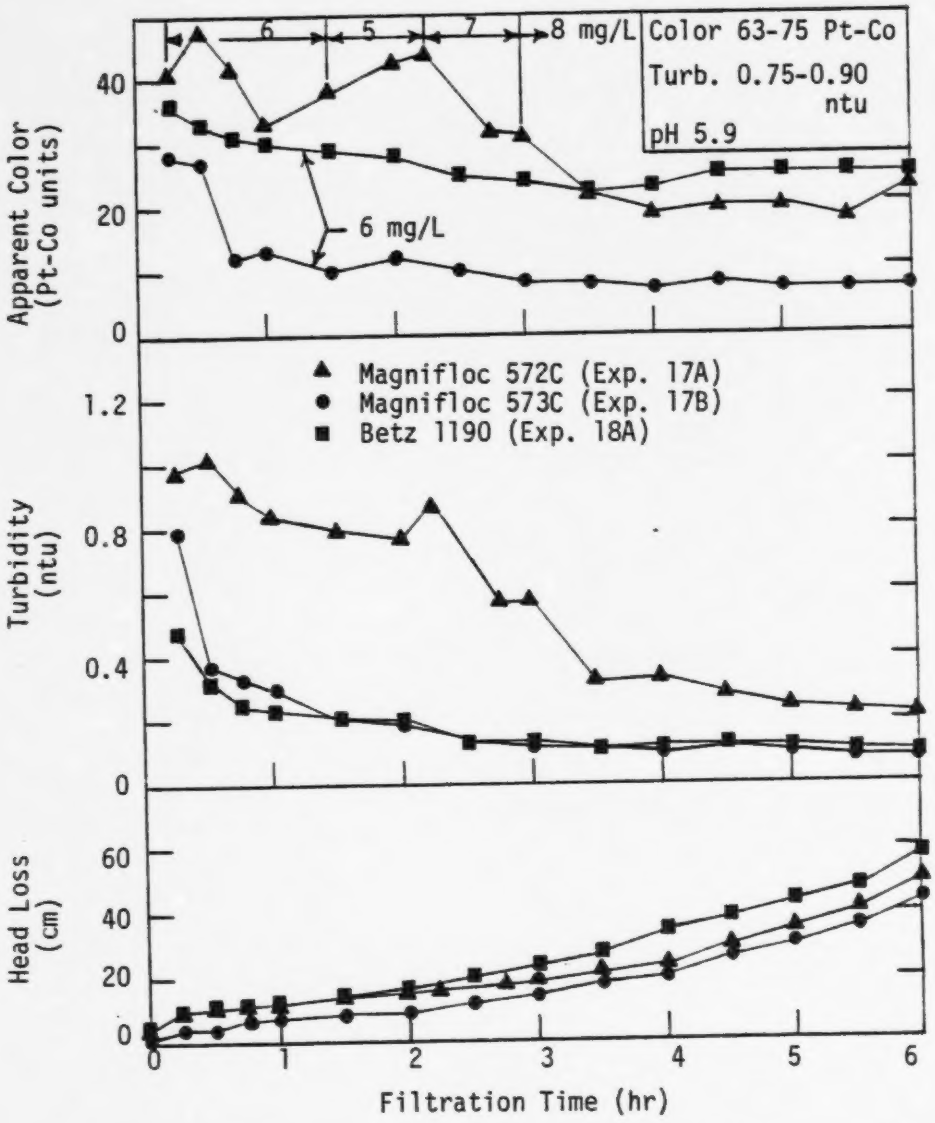

Figure 55. Small scale filter results comparing three cationic polyelectrolytes (exps. 17A, 17B, 18A).

bed ripening. However, Magnifloc 573C produced better effluent in terms of apparent color than Betz 1190 (7-10 Pt-Co units for 573C vs. 18-25 Pt-Co units for 1190). Experiment 17B, using Magnifloc 573C, also exhibited slightly slower head loss development than the other two experiments. Based on these results, Magnifloc 573C was selected for use in all subsequent polymer filter experiments.

One other small scale experiment using Magnifloc 573C was conducted to verify its performance prior to use in the Waterboy experiments. This experiment (20A) was conducted in January when the Glenmore Reservoir was ice-covered. Raw water qulaity was much better than for the previously discussed small scale polymer experiments conducted in October. Raw water quality parameters in January included an apparent color of 38 Pt-Co units, a turbidity of 0.74 ntu, a total UV (254 nm) absorbance of 0.105 cm^{-1}, and a temperature during the experiment of 13°C. The filter results are presented in Figure 56. The required Magnifloc 573C dosage was 2.5 mg/L, which is 2.4 times less than the 6.0 mg/L required in October. These polymer dosages correspond to charge dosages of 10.7 μeq/L in January, compared to 25.8 μeq/L in October (charge dosages calculated from data in Table 29). Good results were obtained for 15 hours, at which time the experiment was terminated. Effluent apparent color and turbidities of 5-8 Pt-Co units and ~0.10 ntu, respectively, were obtained after the proper dosage was found. Only 80 cm of head loss had developed after 15 hours.

Alum--

Seven small scale filter experiments were conducted using alum as the primary coagulant. Samples for raw and effluent aluminum were collected and analyzed for the alum experiments (see Table 39). Note that the raw water contained aluminum at a concentration of 0.08 mg/L on two occasions. In this study, a filtered water criterion for aluminum of 0.10 mg/L was used.

Figure 57 presents the results of the first alum experiment (15B). This experiment was conducted in July under summer raw water quality conditions. Raw water quality parameters include an apparent color of 56 Pt-Co units, a turbidity of 1.0 ntu, a total UV (254 nm) absorbance of 0.180 cm^{-1}, and a temperature of 20°C. A dosage of 12 mg/L had been predicted from a jar test. This dosage was used for the first 4 hours of the experiment with good results (apparent color 18-20 Pt-Co, turbidity 0.12-0.18 ntu). At the 3-hour mark, the alum feed was disrupted temporarily due to a pump malfunction. The effluent quality was seen to deteriorate quickly, but recovered quickly once the alum feed was restored. After 4 hours, the alum dosage was reduced to 10 mg/L to evaluate performance at a slightly underdosed condition as indicated by the jar test. Effluent quality deteriorated rapidly, with apparent color and turbidity increasing to approximately 26 Pt-Co units and 0.4 ntu, respectively. A sample for residual aluminum was taken when the experiment was working well, and a concentration of 0.18 mg Al/L was measured. A second sample was taken at the slightly underdosed condition, and a residual aluminum concentration of 0.21 mg/L was measured. The raw water aluminum concentration was 0.05 mg/L.

Experiment 16B (Figure 58) was designed to compare results with experiment 15B to determine if the addition of a small amount of cationic

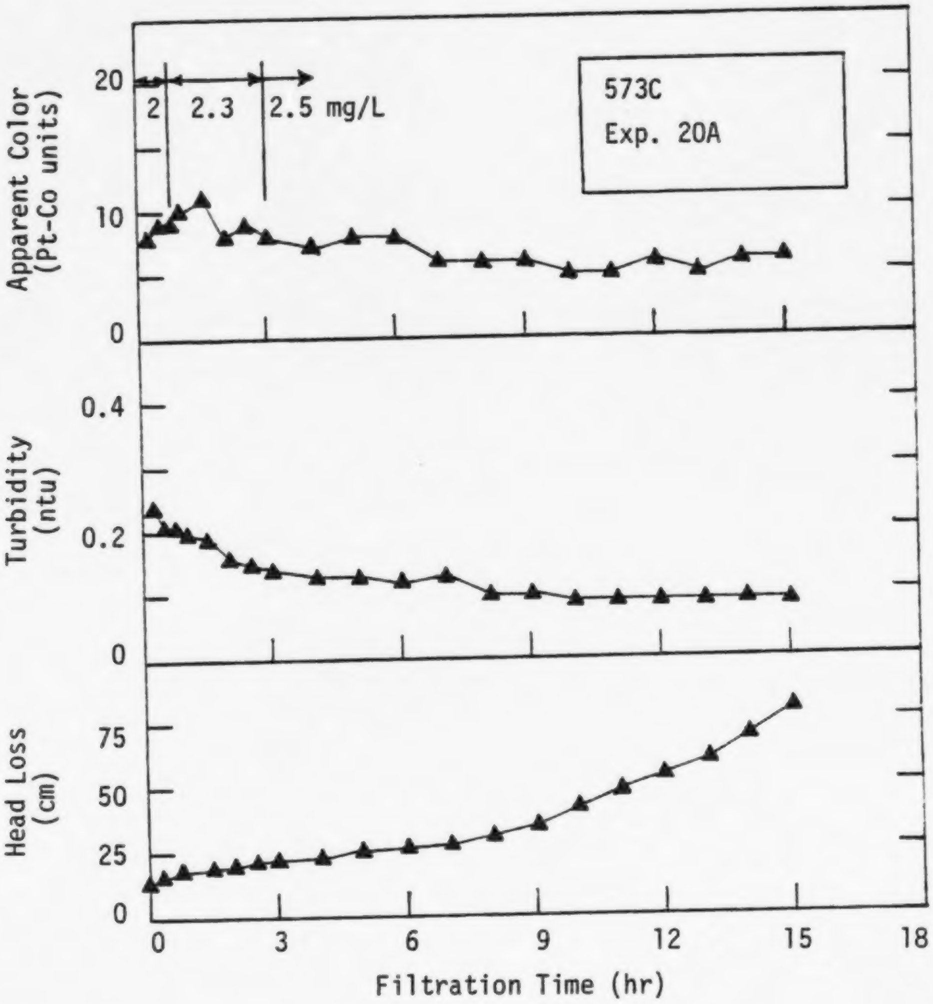

Figure 56. Small scale filter results for Magnifloc 573C (exp. 20A).

TABLE 39. ALUMINUM DATA FOR FILTER EXPERIMENTS

Exp. No.	Raw Water Aluminum (mg/L)	Filtered Water Aluminum (mg/L)	Comments
15B	0.05	0.18 0.21	slight overdose
16B	0.05	0.18 0.19	
18B	0.08	0.14 0.16	
19A	0.08	0.05 0.09	
19B	0.08	0.06 0.07	
21A	0.03	0.29 0.15	
21B	0.03	ND	
7P	ND	0.05 0.03 0.05	
8P	ND	0.07 0.09	

ND - less than detection limit of 0.01 mg/L

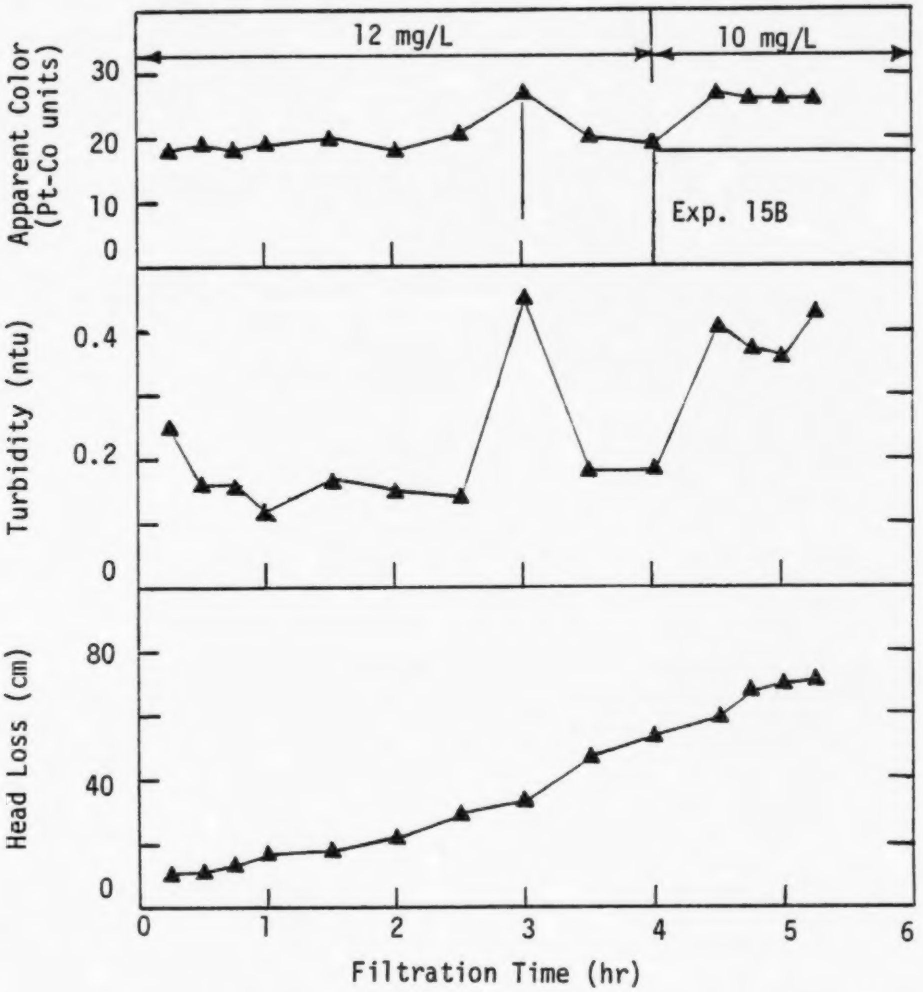

Figure 57. Small scale filter results for alum (exp. 15B).

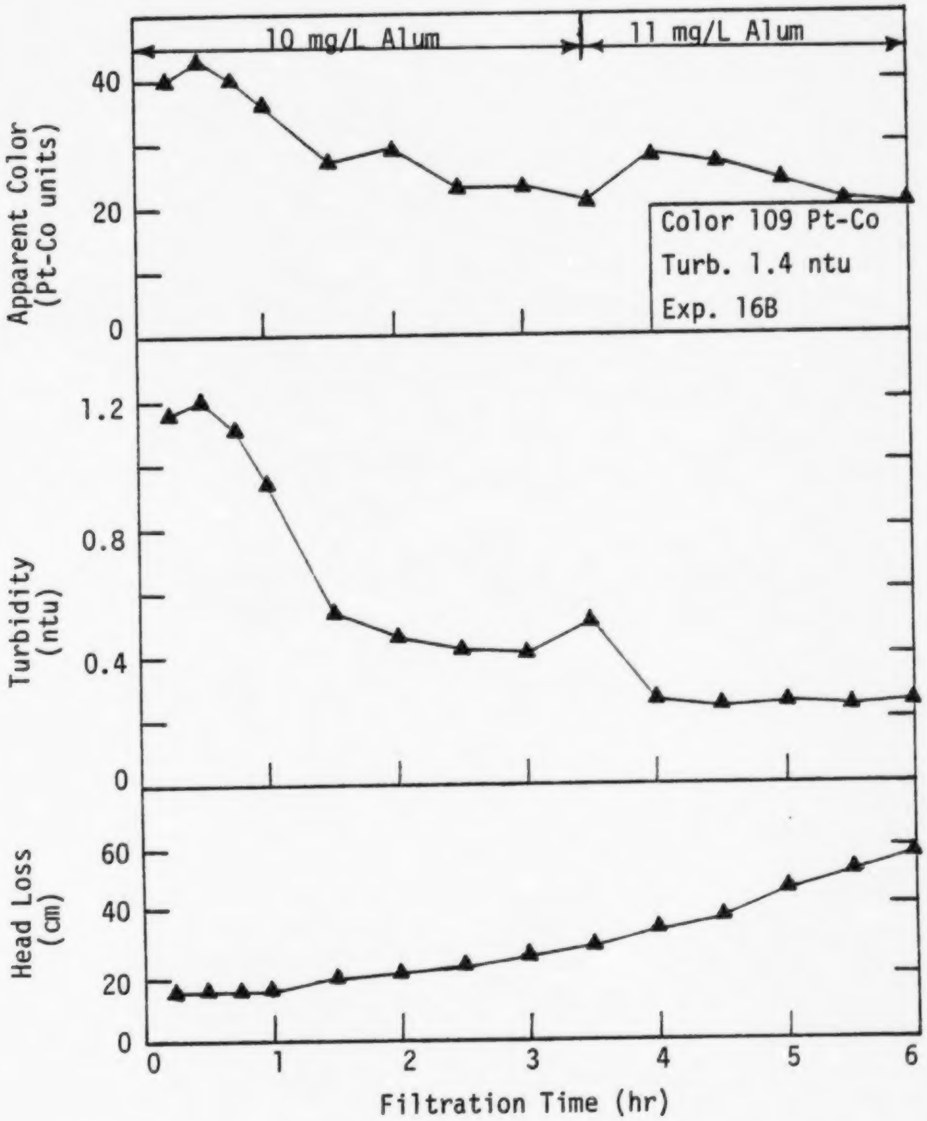

Figure 58. Small scale filter results for 1 mg/L Magnifloc 573C plus alum (exp. 16B).

polymer could reduce the required alum dosage. The raw water quality for this experiment was slightly worse than for experiment 15B for all parameters except UV absorbance (apparent color 109 Pt-Co units, turbidity 1.4 ntu, total UV (254 nm) 0.160 cm^{-1}). Approximately 1 mg/L of Magnifloc 573C was added in the raw water reservoir. An initial alum dosage of 10 mg/L was tried, with poor results. When the alum dosage was increased to 11 mg/L, effluent turbidity improved considerably. These results indicate that, even with a slightly poorer quality raw water, the alum dosage was reduced slightly by addition of a cationic polymer. Residual aluminum concentrations of 0.18 and 0.19 mg/L were measured at the higher alum dosage, with a raw water concentration of 0.05 mg/L.

Another alum experiment was conducted in October to evaluate performance during fall overturn raw water conditions (apparent color 75 Pt-Co units, turbidity 0.90 ntu, total UV (254 nm) 0.169 cm^{-1}). The results are presented in Figure 59. An alum dosage of 14-15 mg/L was found to perform satisfactorily. This compares with a dosage of 12 mg/L in July (run 15B). Effluent apparent color of 17-19 Pt-Co units and turbidities of 0.13-0.18 ntu were obtained. Residual aluminum values of 0.14 and 0.16 mg/L were measured with a raw water value of 0.08 mg/L.

Experiments 19A and 19B were conducted to study the effects of the use of a nonionic polymer as a filter aid. Both experiments were conducted in the in-line mode at pH 5.7. These two experiments were conducted under winter raw water conditions (apparent color 38 Pt-Co units, turbidity 0.74 ntu, total UV (254 nm) 0.105 cm^{-1}). The results are presented in Figure 60. Experiment 19A was conducted with alum alone. In experiment 19B the same alum dosage (12 mg/L) was used, but 0.1 mg/L of Magnifloc 985N was added after flocculation. A contact time of 24 minutes was provided following alum addition with slow mixing in a flocculation chamber. However, this experiment is not considered to be in the flocculation mode since the water passed through a static mixer after the addition of the polymer (985N) filter aid. Results indicate effluent quality was similar for the two experiments (apparent color 5-7 Pt-Co units, turbidities 0.04-0.09 ntu). However, in experiment 19A with alum alone, there was turbidity breakthrough after 12 hours when the total head loss was 170 cm. In experiment 19B with the filter aid, there was no turbidity breakthrough, and a head loss of 200 cm was reached after 12 hours. The results indicate that premature turbidity breakthrough was prevented by the addition of a filter aid. However, the length of the filter run was not increased due to slightly faster head loss development when the filter aid was applied. Residual aluminum concentrations of 0.05 and 0.09 mg/L were measured for experiment 19A, and 0.06 and 0.07 mg/L for experiment 19B, with a raw water aluminum concentration of 0.08 mg/L.

Figure 61 presents the results of two similar experiments to 19A and 19B except these two (21A and 21B) were conducted in the flocculation mode. These two experiments were also conducted under winter raw water conditions. The raw water quality was slightly better than for experiments 19A and 19B, with values of 26 Pt-Co units for apparent color, 0.67 ntu for turbidity and 0.094 cm^{-1} for total UV (254 nm). The water temperature during filtration

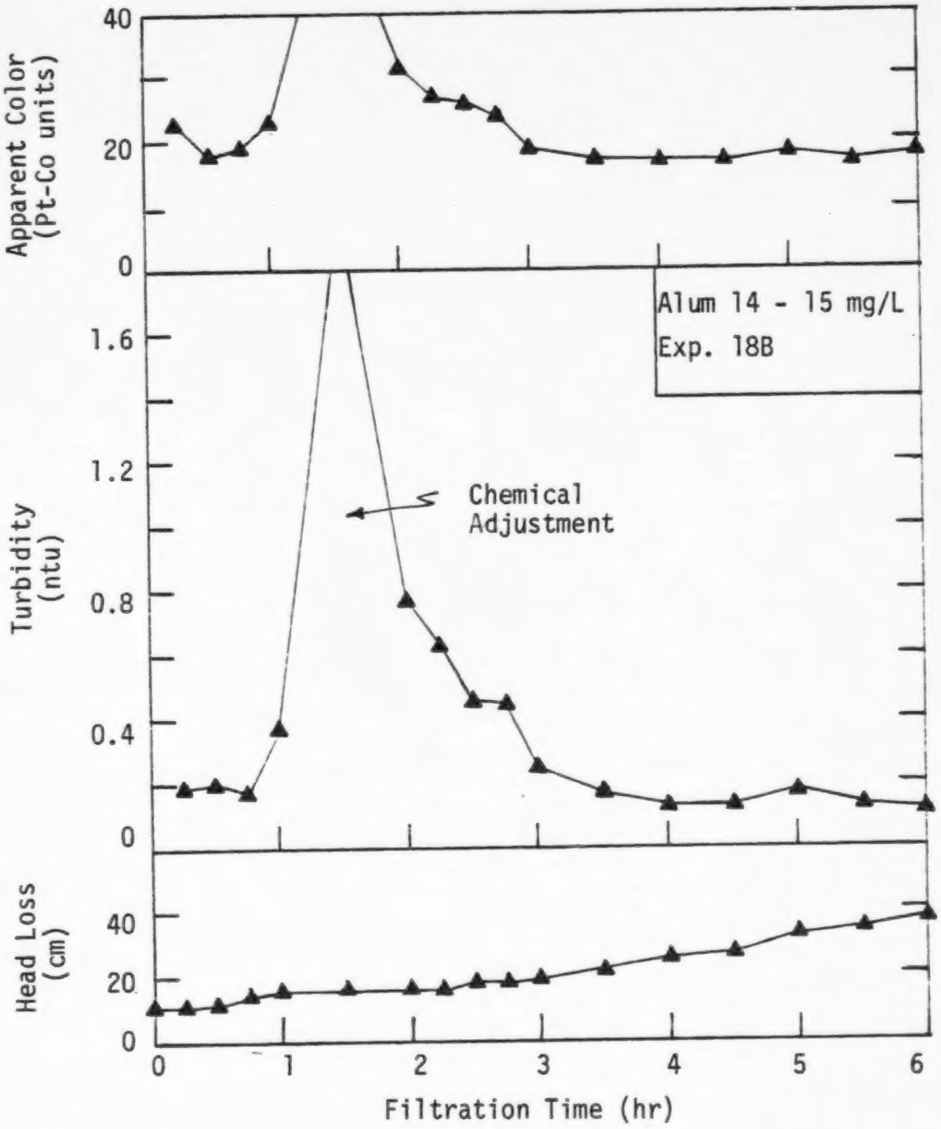

Figure 59. Small scale filter results for alum during fall overturn conditions in Glenmore Reservoir (exp. 18B).

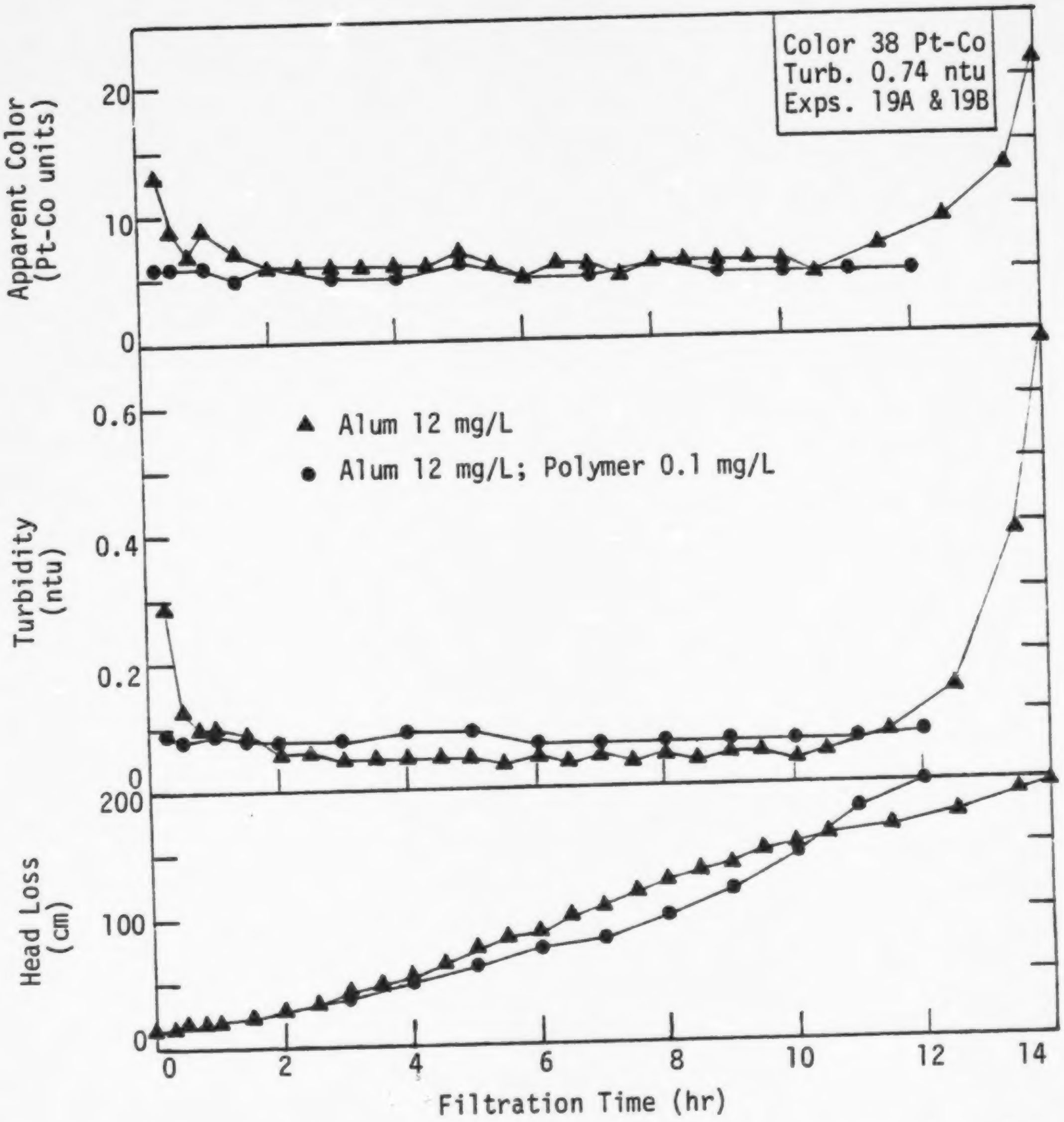

Figure 60. Small scale in-line filtration results comparing alum (exp. 19A) against alum plus a nonionic polymer (exp. 19B).

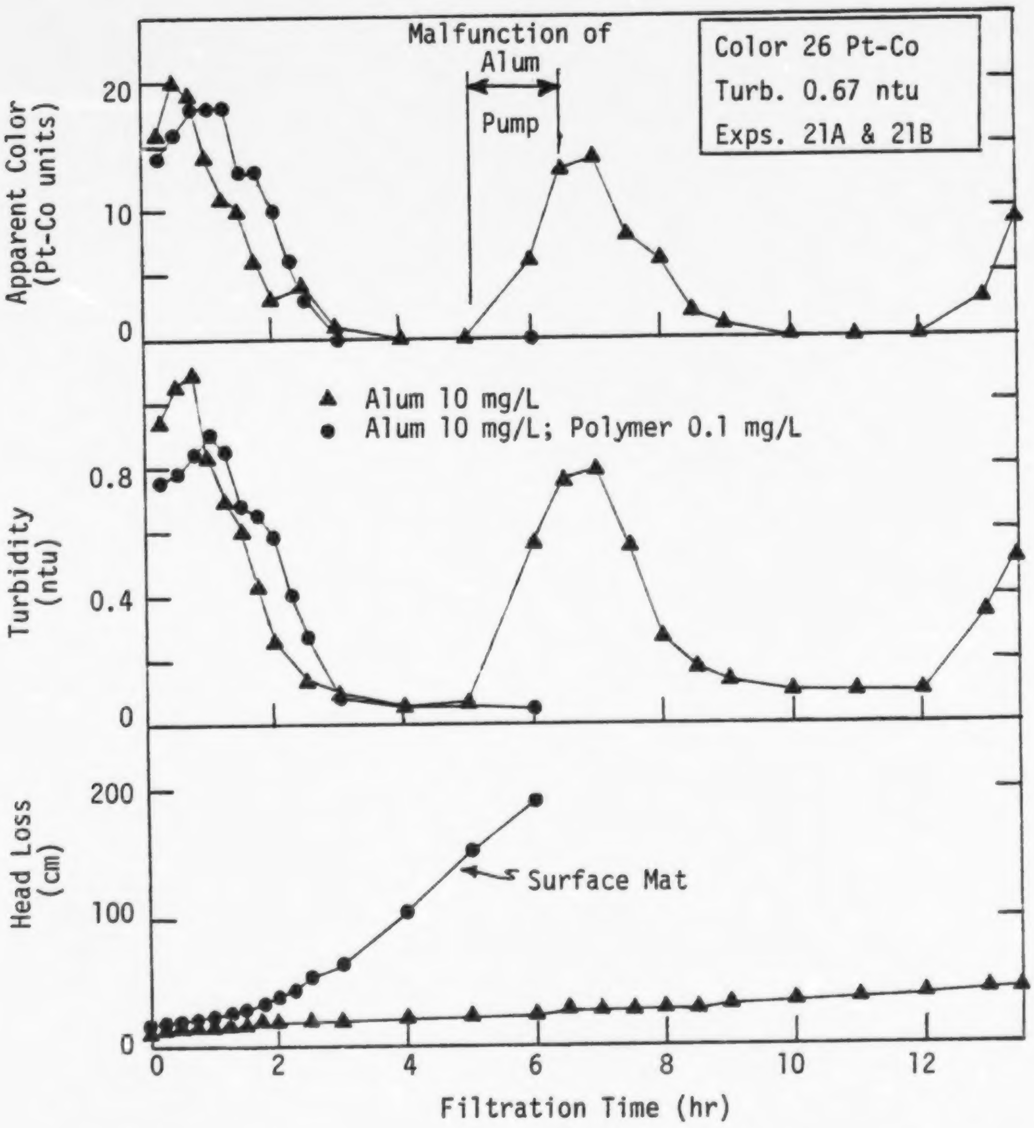

Figure 61. Small scale results for filtration with flocculation using alum (exp. 21A) and alum plus a nonionic polymer (exp. 21B).

was also lower for experiments 21A and 21B, especially 21A which was conducted at 7°C. A flocculation time of 48 minutes was provided for both experiments.

The required alum dosage for both experiments was only 10 mg/L. Experiment 21A was conducted with no filter aid, whereas 0.1 mg/L of Magnifloc 985N was applied at the top of the filter column in experiment 21B. Both yielded excellent effluent quality, with apparent color of less than 5 Pt-Co units and turbidities of 0.05-0.10 ntu. Residual aluminum concentrations of 0.29 and 0.15 mg/L were measured for experiment 21A. For experiment 21B, the residual aluminum concentration was less than the detection limit of 0.01 mg/L. The raw water aluminum concentration was 0.03 mg/L.

Filter bed ripening was slow in both cases which contrasts with the in-line filtration experiments. In experiment 21A, the alum feed pump malfunctioned at the 5-hr point, and it took another two hours for the filter to ripen again. Breakthrough of turbidity and color occurred after 12 hours of total operation. In experiment 21B, a visible mat of floc formed on top of the filter plugging it, and the experiment had to be terminated after only 6 hours due to head loss development.

The effect of flocculation on head loss development may be evaluated by comparing experiments 19A (in-line) and 21A (flocculation). After 12 hours of operation, the in-line experiment had 170 cm of head loss. By comparison, the flocculation experiment had only 38 cm of head loss after 12 hours. It should be noted that the flocculation experiment was operating satisfactorily for only 8 of these 12 hours, due to ripening and a malfunction of the alum feed pump. Also, the raw water quality was slightly better for the flocculation experiment, and the alum dosage was less (10 vs. 12 mg/L). Despite these factors, the reduction in head loss development with flocculation is still very evident. Both experiments exhibited turbidity and color breakthrough at approximately the 12-hour point.

Large Scale (Waterboy) Direct Filtration Experiments

Seven large scale filter experiments were conducted using the Waterboy pilot plant between May 11 and June 13, 1982. A summary of operating conditons for these experiments is presented in Table 40. Raw water quality data can be found for the appropriate dates in Table 14. All experiments were conducted at a filtration rate of 9.76 m/hr. Experiments were generally terminated when either turbidity breakthrough occurred, or when 2.1 m (7 ft) of total head loss was reached. Filtration performance with respect to apparent color, turbidity, head loss, and net water production will be discussed first. Organics removals will be discussed later using the combined data of the small scale and large scale experiments.

Cationic Polymer--

This section examines filtration performance for experiments in which a cationic polymer (Magnifloc 573C) was used as the primary coagulant.

Effect of polymer dose--A Waterboy experiment (15P) was conducted to demonstrate the effects of polymer dosage on filter performance. A dosage of

TABLE 40. SUMMARY OF WATERBOY FILTER EXPERIMENTS (Flow 1.01 L/sec, Filt. Rate 9.76 m/hr. for all experiments) ONEIDA, N.Y.

No.	Date	Coagulant	Dosage (mg/L)	pH	Temp (°C)	Static Mixers G (s^{-1})	Floc Period (min)	Floc G (s^{-1})
4P	5/11/82	573C	3.0	5.6	12	1493	-	-
5P	5/12/82	573C	3.0	5.6	12	1493	9.2	70
6P	5/14/82	573C	3.0-3.5	Varied	13	1505	-	-
7P	5/17/82	Alum	11.5	6.0[+]	13	1505	-	-
8P	5/18/82	Alum	15	Unadjst[‡]	13	1505	-	-
14P	6/12/82	573C, 1160[*]	5.0, 0.1[*]	5.5	14	1516	9.2	70
15P	6/13/82	573C	Varied	5.5	14	1516	-	-

[*] Betz 1160 applied at top of filter box

[+] Raw pH adjusted to 6.0 prior to alum addition; Effluent pH = 5.8-5.9

[‡] Raw pH = 6.9; Effluent pH = 6.6

5 mg/L of Magnifloc 573C was selected as the "optimum" dosage from a jar test and previous experiments. Four polymer dosages were applied and the results are presented in Figure 62. First an underdose of 2.5 mg/L was applied. Effluent quality was poor with respect to both color and turbidity (apparent color 26-34 Pt-Co units, turbidity 0.75-1.5 ntu). The polymer dosage was then increased to the "optimum" dosage of 5 mg/L, and effluent quality improved rapidly (apparent color 15-16 Pt-Co units, turbidity 0.25 ntu). A slightly overdosed condition of 8 mg/L was then tested. Turbidity deteriorated rapidly (~1.0 ntu). At a polymer dosage of 12 mg/L, overdosing clearly occurred with turbidities of about 3.5 ntu and apparent color values of 30 Pt-Co units. These results agree with those presented earlier in this Section. They show that direct filtration behaves in an analagous fashion to jar tests with underdosing, good destabilization, and overdosing.

pH--pH was held constant at approximately 5.5 to 6 for most of the Waterboy experiments. One experiment (6P) was performed, however, in which pH was varied during the course of the filter run. Four pH conditions were tested - 5, 5.5, 6.1 and 6.8 (raw water unadjusted pH). The experiment was conducted in the in-line mode.

The results are presented in Figure 63. From jar tests conducted at pH 5.5, a polymer dosage of 3 mg/L was selected. This polymer dosage was used in the first 6 hours of the filter run when the pH was either 5 or 5.5 Performance at pH 5.0 was excellent, after an initial ripening period of about 1 hour, in terms of filtered water color and turbidity (apparent color 4-6 Pt-Co units, turbidity 0.12-0.18 ntu). When the pH was adjusted to 5.5, effluent quality deteriorated slightly, but was still quite good (apparent color 10-17 Pt-Co units, turbidity 0.28-0.30 ntu). The pH was then adjusted to 6.1, and the polymer dosage was increased slightly to 3.5 mg/L. This was done because the net negative charge on the colloidal particles should increase as pH is increased. Therefore, a larger dosage of cationic polymer would be required to neutralize the increased negative charge. However, the effluent quality deteriorated with apparent color of 14-16 Pt-Co units and turbidity of 0.46-0.52 ntu. With no pH adjustment (pH of 6.8), effluent quality deteriorated to unacceptable levels of color and turbidity (apparent color 22-24 Pt-Co units, turbidity 0.65-0.73 ntu).

Additional experiments investigating the effect of pH were not performed. Based on the pilot plant results for the Grasse River, it is believed that cationic polymers can treat Glenmore Reservoir water without pH adjustment (i.e., at pH around 7). It is noted, however, that it is more difficult to choose polymer dosages (narrower range of good operation) for the Glenmore Reservoir which is a high quality water (low turbidity, low color, low organics).

In-line vs. flocculation--A pair of experiments were conducted on consecutive days to study the effects of flocculation on filter performance. The raw water quality for these two experiments was essentially the same as shown for the dates 5/11/82 (experiment 4P) and 5/12/82 (experiment 5P) in Table 14. Experiment 4P was conducted in the in-line mode. Experiment 5P was conducted in the flocculation mode with a velocity gradient (G) of

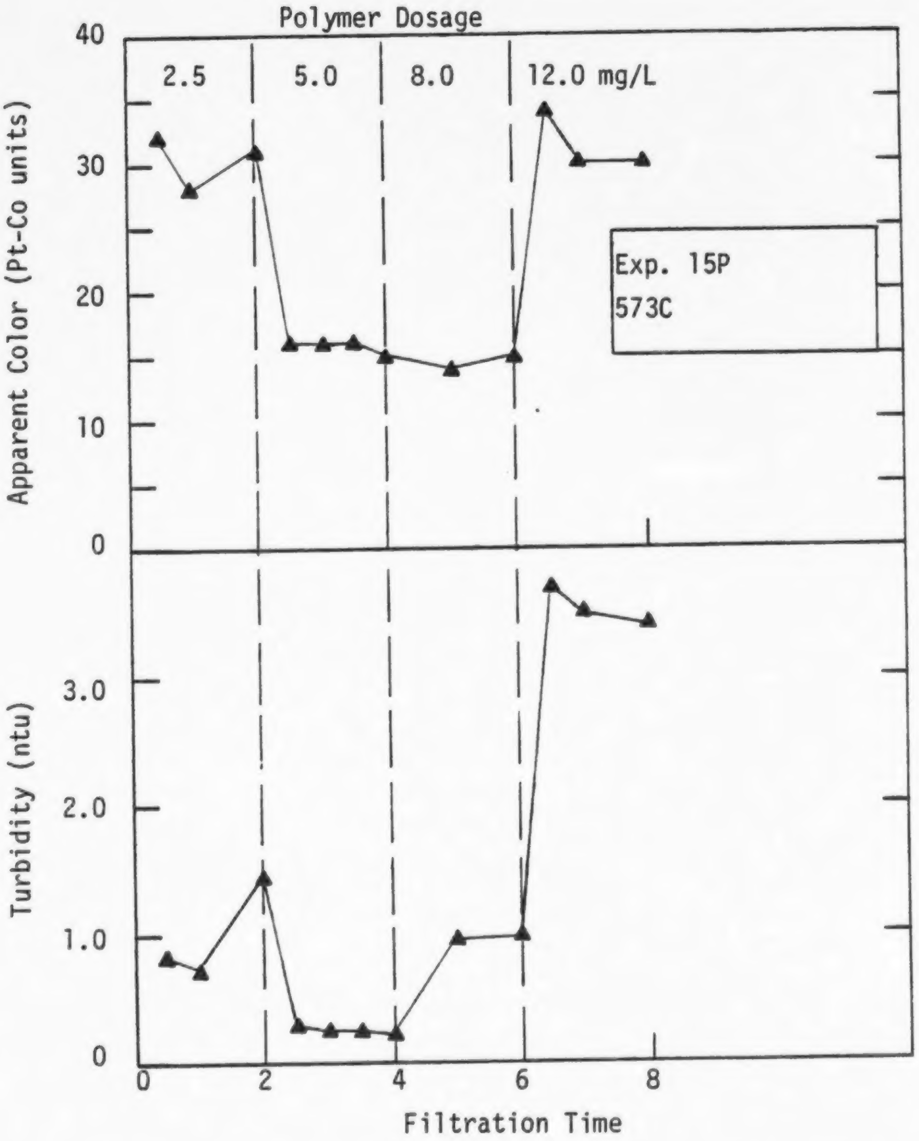

Figure 62. Effects of polymer dose on filter performance (exp. 15P).

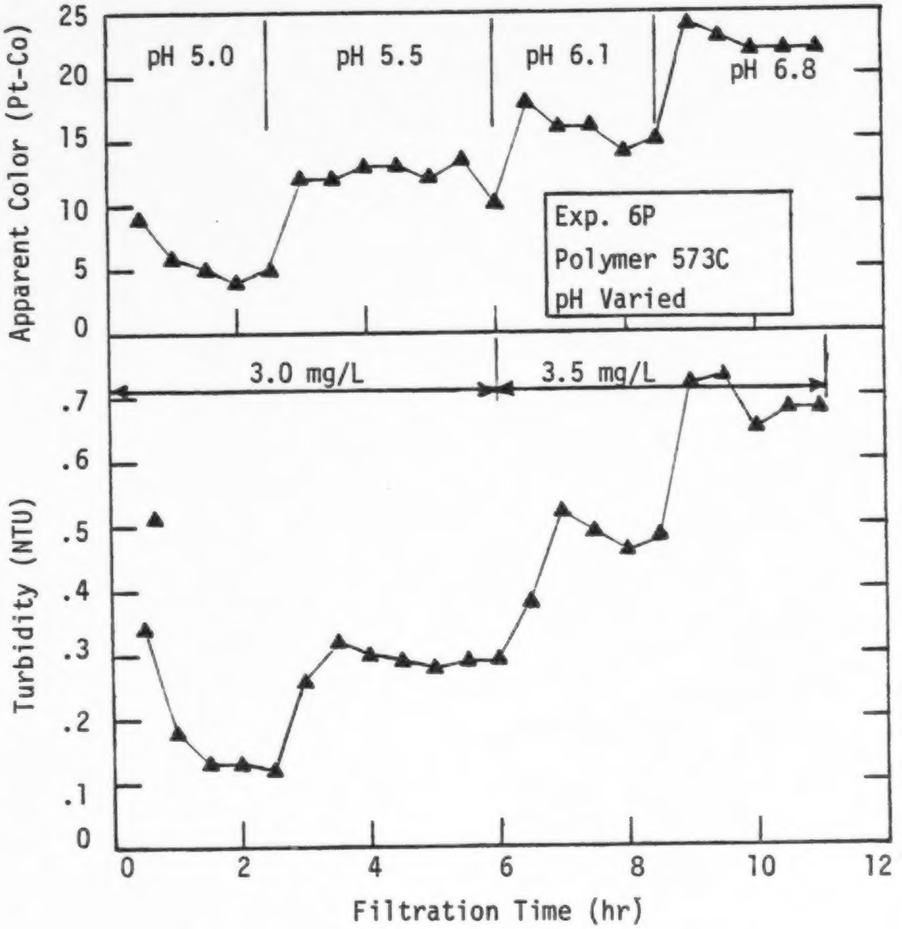

Figure 63. Direct filtration results for exp. 6P at various pH conditions.

70 s^{-1} and a flocculation tank detention time of 9.2 minutes.

Results are presented in Figure 64. A polymer dosage of 3 mg/L was used for both experiments, after adjustment during the early stages of experiment 4P. This corresponds to a charge dosage of 12.9 μeq/L. Effluent quality was similar for both experiments, with apparent color and turbidity values fo 5-10 Pt-Co units and 0.2-0.28 ntu, respectively. Experiment 4P (in-line) was stopped after 16 hours due to time constraints, while experiment 5P (flocculation) was terminated when turbidity breaktrhough occurred. Effluent turbidity exceeded the criterion of 0.3 ntu after 31 hours of operation. During the 31 hours, 29,760 gallons of water were produced. When the backwash water of 2,640 gallons is subtracted, a net water production of 27,120 gallons is obtained. Net water production data for this and several other Waterboy experiments are summarized in Table 41.

TABLE 41. NET WATER PRODUCTION FOR WATERBOY EXPERIMENTS (ONEIDA, N.Y.)

Exp. No.	Length of Run (hrs)	Reason for Termination	Total Water Produced (gal)	Backwash Water (gal)	Net Water Production (gal)
5P	31	Turbidity of 0.3 ntu	29,760	2,640	27,120
14P	25	2.1 m of head loss	24,000	2,640	21,360
7P	14	Turbidity of 0.3 ntu	13,440	2,640	10,800
8P	9	Turbidity of 0.3 ntu	8,640	2,200	6,440

Examination of the total head loss data for these two experiments reveals that head loss development was slightly lower when flocculation was provided. This phenomenon was observed for the Canton experiments previously reported. During flocculation, small particles (singlets) are aggregated into larger particles. The surface area of the retained particles is therefore reduced by flocculation, and resistance to flow is reduced.

To further understand the effects of flocculation, head loss distribution across the filter bed was examined. Head loss distribution plots at various elapsed filtration times for experiment 4P are presented in Figure 65. At termination of the run, 25 percent of the total head loss was occurring between the top of the filter bed and tap #2, which consists of the top 19 cm of anthracite. In the next section (tap #2 to tap #3), which consists of 24.4 cm of anthracite, 20 percent of the total head loss was occurring. Between taps 3 and 4, which consists of the bottom 7.4 cm of anthracite and

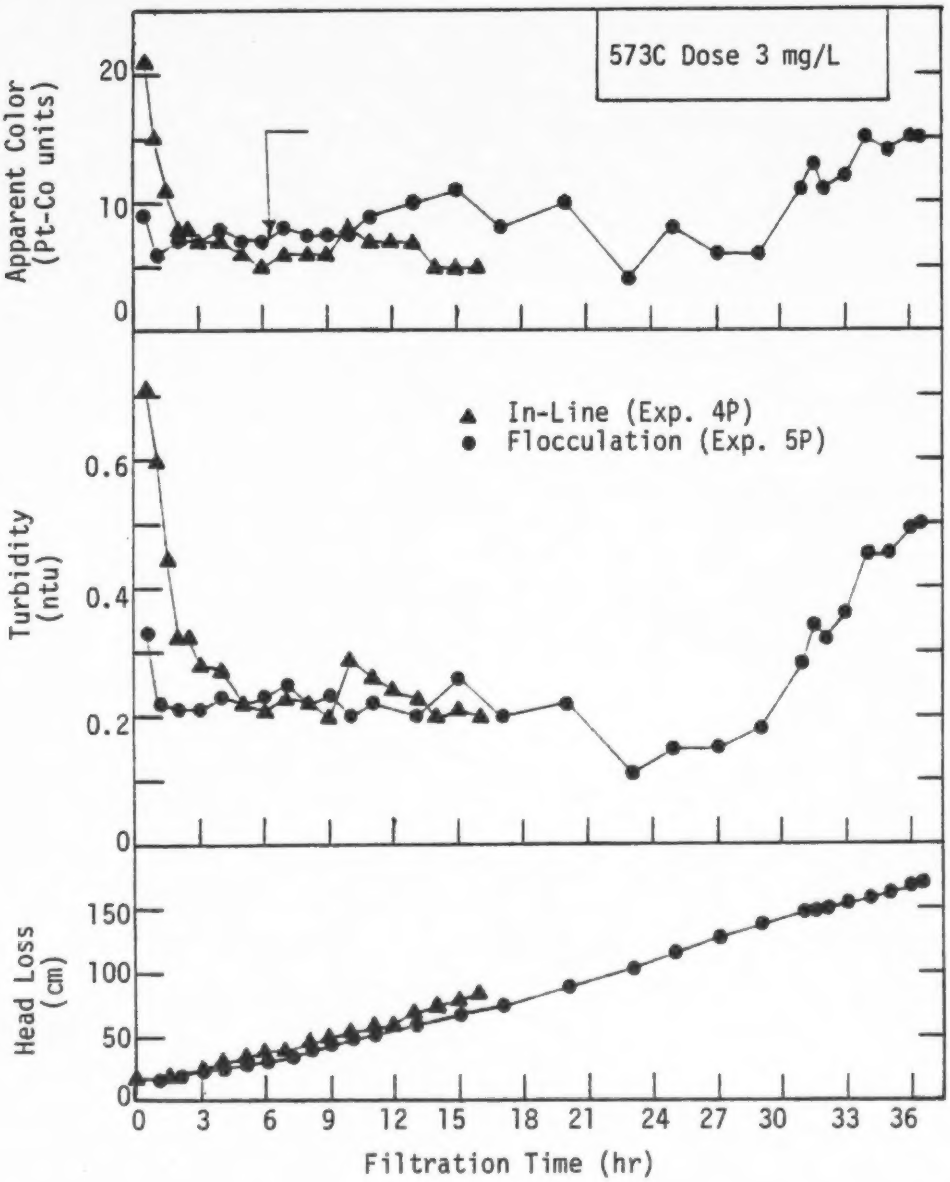

Figure 64. Comparison of in-line filtration vs. flocculation at rate of 9.76 m/hr (exps. 4P, 5P).

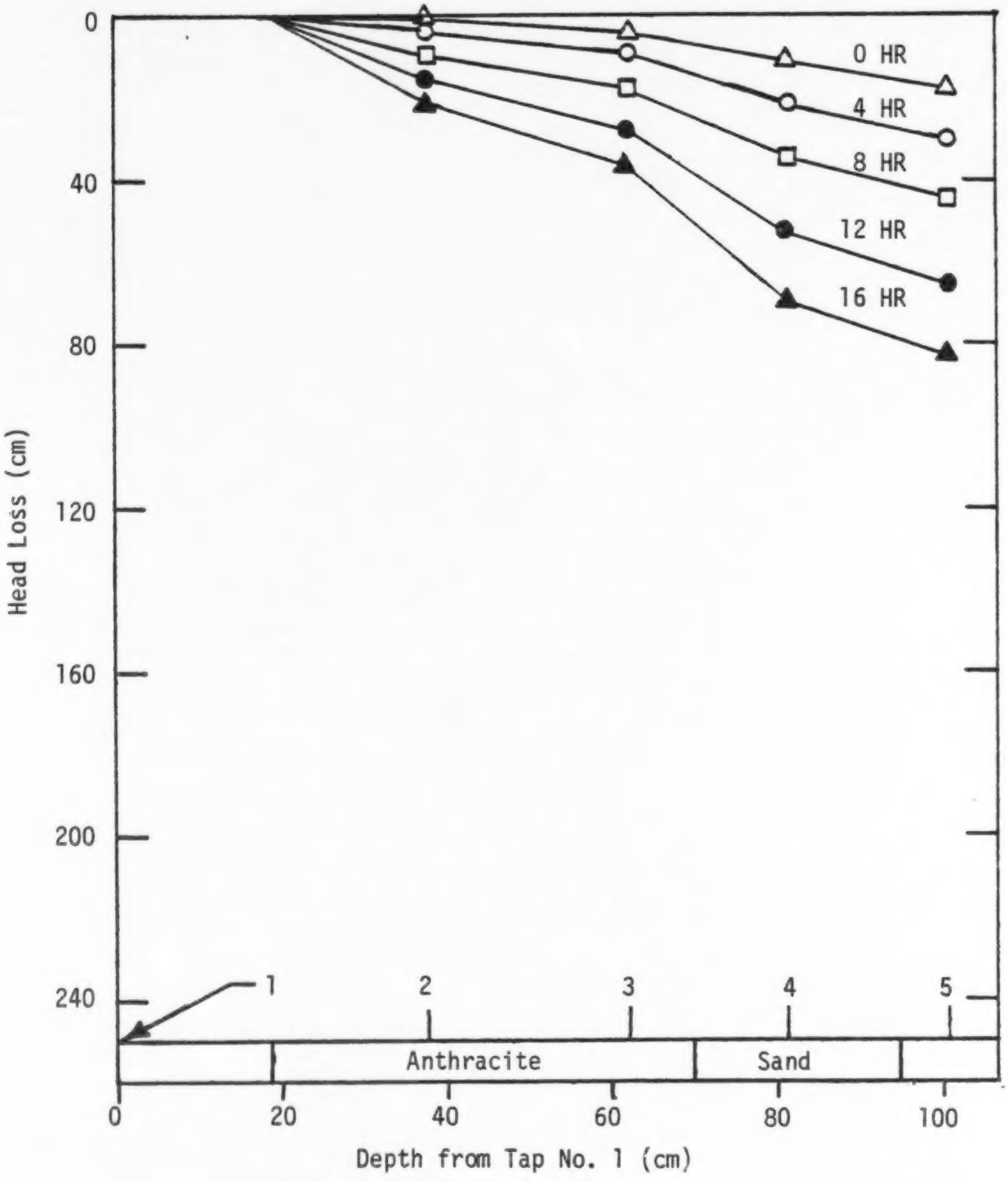

Figure 65. Head loss distributions as a function of filtration time for in-line filtration at rate of 9.76 m/hr (exp. 4P).

the top 11.6 cm of sand, 39% of the total head loss was occurring. The remaining 16% of the head loss was occurring between taps 4 and 5, which corresponds to 13.8 cm of sand and 5.9 cm of gravel. This implies that much of the removal was being accomplished by the bottom portion of the anthracite and top portion of the sand. Apparently, particle removal was inefficient in the upper portion of the bed, since a large portion of the particles penetrated through the anthracite and were removed by the sand. In general, this is undesirable since the solids storage capacity of the anthracite was not being fully utilized.

Similar head loss distribution plots for experiment 5P (flocculation) are presented in Figure 66. In the early part of the filter experiment (0-10 hours), head loss development was fairly evenly distributed throughout the bed. After this period, a large portion of the head loss again accumulated in the lower portion of the bed. At termination, 38 percent of the total head loss occurred between taps 3 and 4, with 25 percent in the top section, 22 percent between taps 2 and 3, and 15 percent in the bottom section. Examination of head loss distributions for experiments 4P and 5P reveals head loss distributions for the in-line and flocculation modes are similar, although head loss development was slightly lower in the flocculation mode.

Effects of filter aid--Since for experiment 5P (Magnifloc 573C, flocculation) there was turbidity breakthrough before the desired terminal head loss was reached, a similar experiment was conducted in an attempt to make head loss the limiting factor. To do this, a dosage of 0.1 mg/L of a high molecular weight, very slightly charged, cationic copolymer (Betz 1160) was used as a filter aid. The polymer was fed to the pipe between the flocculator and the filter, just ahead of the filter box. All other conditions were the same as experiment 5P, except for the raw water quality and the required polymer dosage. Experiment 14P (6/12/82) was conducted one month later than experiment 5P (5/12/82); consequently, the raw water quality was different. Apparent color increased from 47 to 73 Pt-Co units, turbidity increased from 1.2 to 1.5 ntu, and total UV (254 nm) increased from 0.124 to 0.250 cm^{-1}. The required polymer dosage increased from 3 to 5 mg/L (21.5 μeq/L on a charge basis).

The results for experiment 14P are presented in Figure 67. Filtered water quality was similar to experiment 5P but with slightly lower turbidities. The filter aid was seen to prevent premature turbidity breakthrough. The filter experiment was terminated after 24 hours when 2.1 m of total head loss had accumulated. Head loss development was faster than experiment 5P. This may be attributed to an increased filter loading due to the higher level of color and organic matter in the raw water, and the increased polymer dosages. Net water production for this experiment was 21,360 gallons, as compared with 27,120 gallons for experiment 5P (see Table 41).

Head loss distributions for experiment 14P at various elapsed times are presented in Figure 68. Examination of this figure reveals that during the first 15 hours of the filter run, most of the removal was occurring in the top portion of the bed. For example, after 10 hours of operation, 53 percent

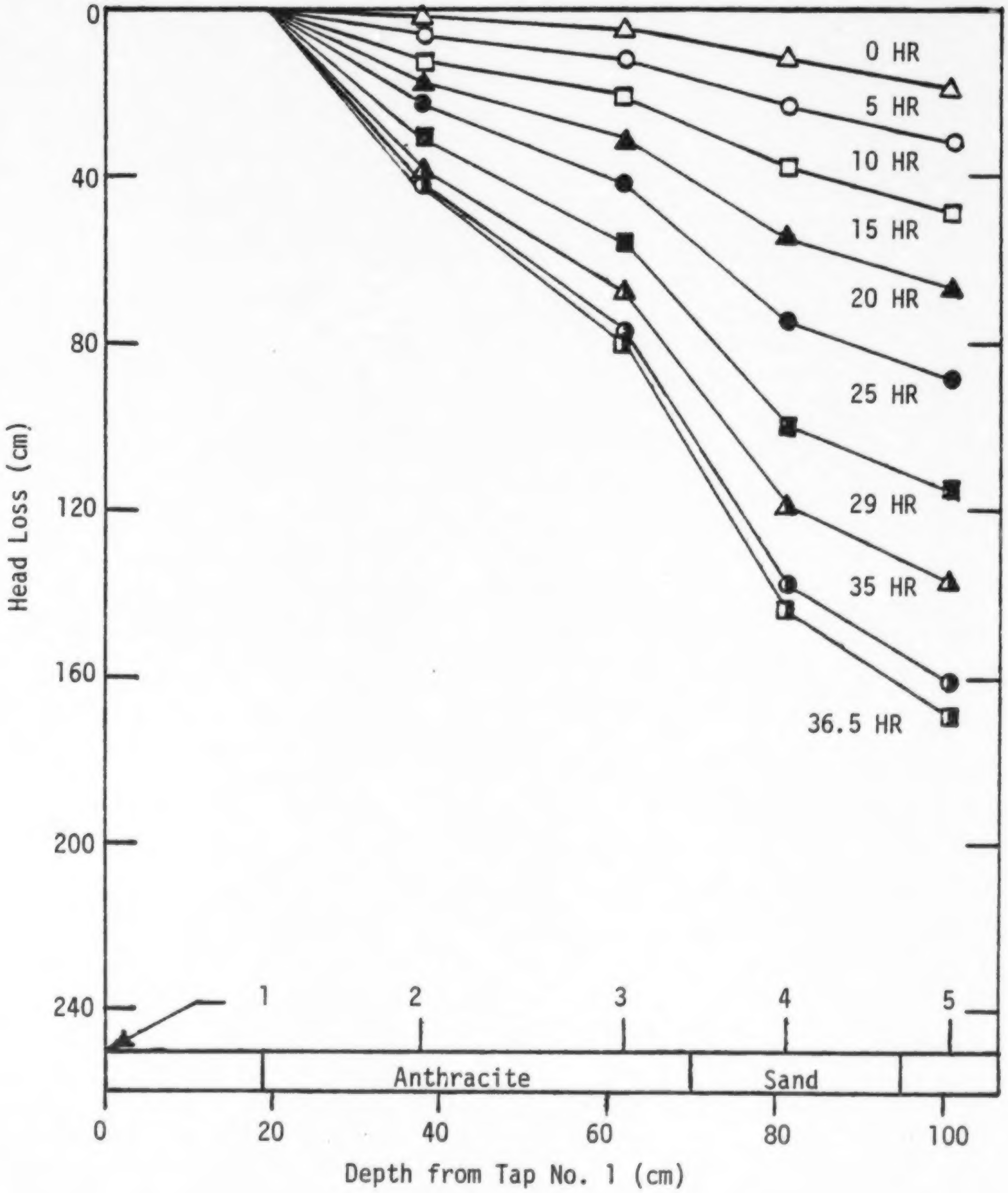

Figure 66. Head loss distributions as a function of filtration time for filtration with flocculation at rate of 9.76 m/hr (exp. 5P).

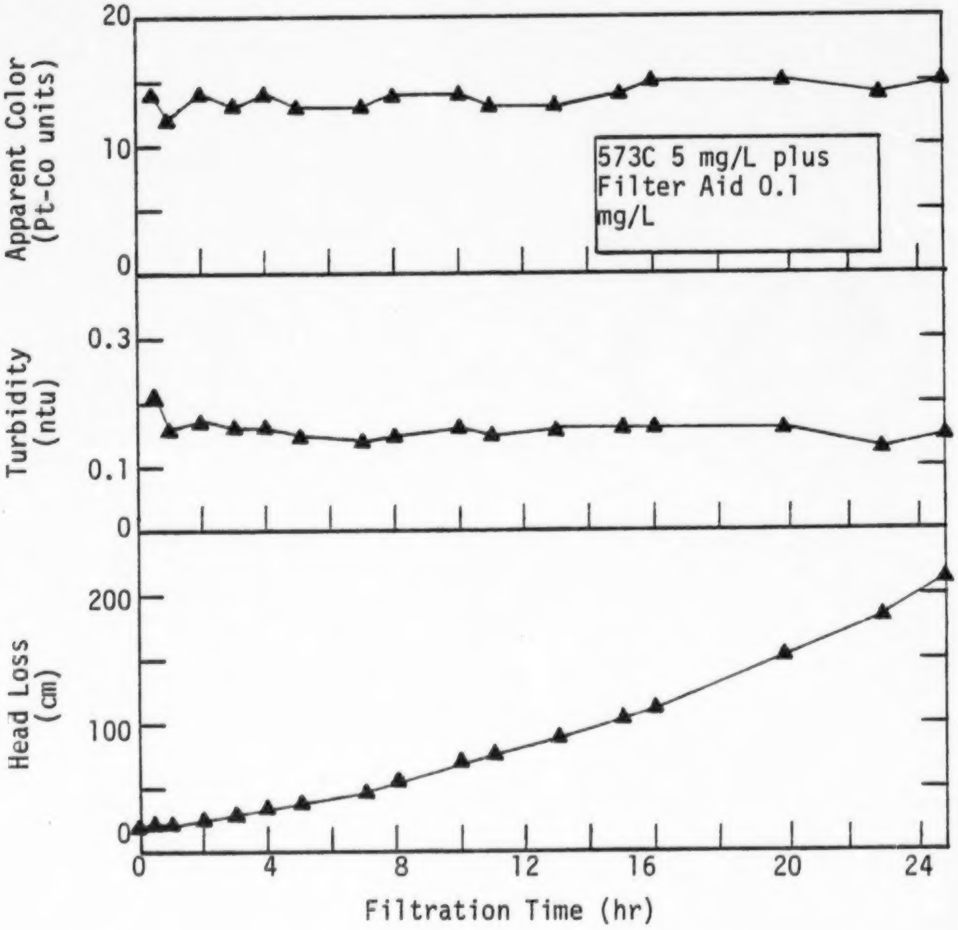

Figure 67. Direct filtration results for Magnifloc 573C plus a filter aid (exp. 14P).

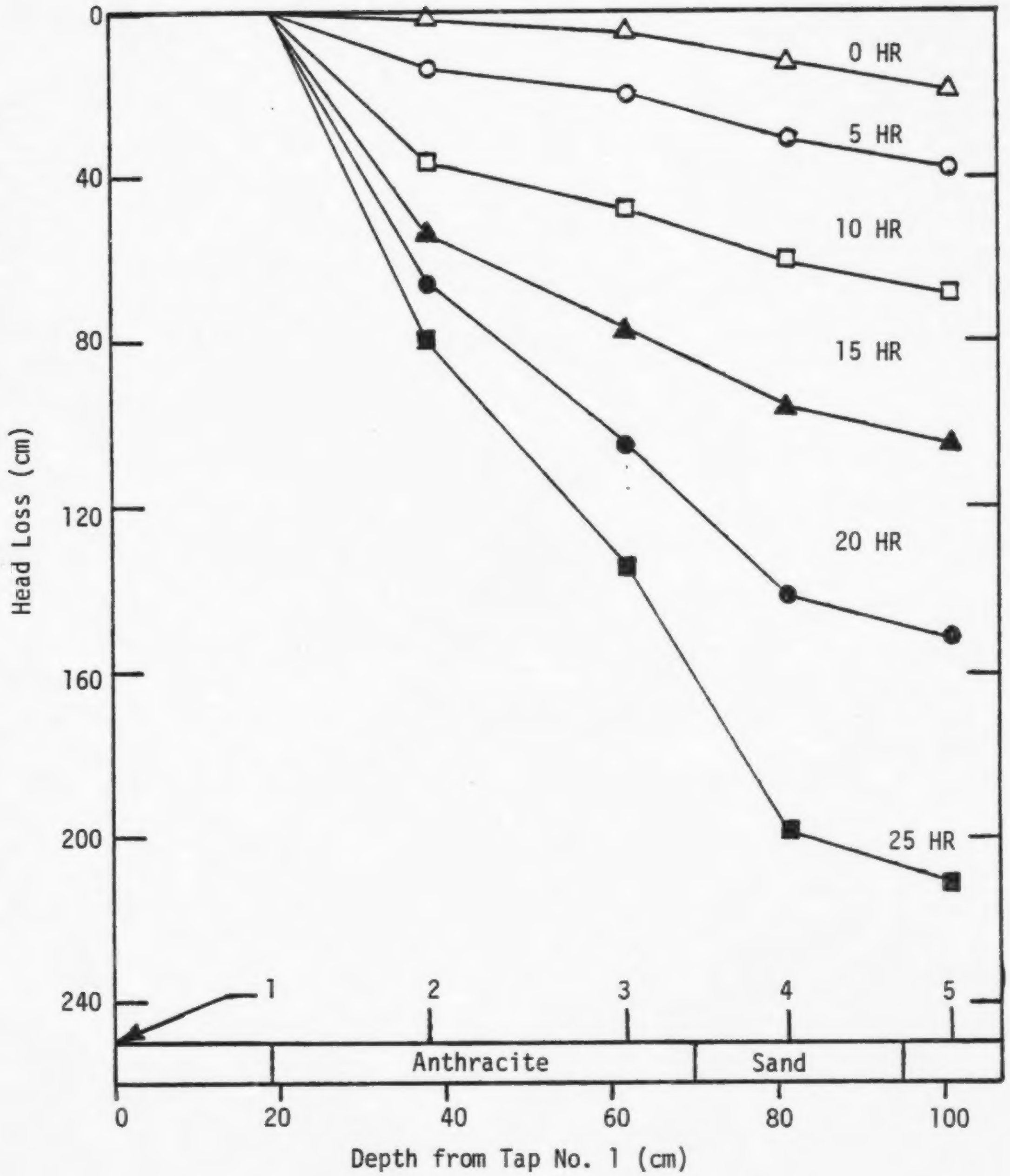

Figure 68. Head loss distributions as a function of filtration time for Magnifloc 573C plus a filter aid (exp. 14P).

of the total head loss was in the top 19 cm of anthracite. After the first 15 hours, most of the removal occurred in the lower portions of the bed. The terminal head loss condition shows nearly equal removals in the top 3 portions of the bed, with 38 percent in the top portion, 26 percent between taps 2 and 3, and 30 percent between taps 3 and 4. Apparently, particle attachment was improved with the addition of the filter aid. As the top portion of the bed became saturated, removal occurred deeper in the bed, and the entire bed depth was utilized.

A comparison of head loss distributions for experiments 5P (Figure 66) and 14P (Figure 68) shows greater head loss in the top of filter bed when the filter aid was used. The filter aid is effective in promoting attachment of particles to the filter media.

Alum--

Two large scale direct filtration experiments were conducted using alum as the primary coagulant (see Table 40). Different pH conditions were investigated. In experiment 7P, the pH of the raw water was adjusted to 6.0 prior to alum addition. The addition of alum at a dosage of 11.5 mg/L dropped the pH of the filter effluent to 5.8 to 5.9. In experiment 8P, the raw water pH was not adjusted. The addition of 15 mg/L of alum dropped the pH from 6.9 (raw water) to 6.6. Both experiments were conducted in the in-line mode. Raw water quality was similar for the two experiments as shown in Table 14 for 5/17/82 (experiment 7P) and 5/18/82 (experiment 8P). Results of these experiments are presented in Figure 69.

Excellent effluent color and turbidities were observed for both experiments (apparent color 1-3 Pt-Co units, turbidity 0.11-0.20 ntu), with no significant difference between the two. A higher alum dosage was required at the higher pH, as would be expected. This higher alum dosage may explain the slightly higher head loss development at the unadjusted pH condition. There was turbidity breakthrough in experimednt 8P (no pH adjustment) after only 9 hours. For experiment 7P (pH adjusted to 6.0), turbidity breakthrough (0.3 ntu or higher) occurred at 14 hours. Net water production values of 10,800 gallons and 6,440 gallons (Table 41) were calculated for the pH 6.0 and the unadjusted pH experiments, respectively.

Head loss distributions for the two alum experiments are presented in Figures 70 and 71. Both exhibit, generally uniform removals throughout the filter bed. Examination of these two figures reveals that head loss distributions are similar, with removal occurring slightly deeper in the bed for the unadjusted pH condition.

Aluminum samples were collected and analyzed for these two experiments (see Table 39). The raw water aluminum concentration for both experiments was less than the detection limit of 0.01 mg/L. For both experiments, effluent aluminum concentrations were below the criterion of 0.10 mg/L.

Additional Waterboy experiments were planned involving alum and use of a filter aid to prevent turbidity breakthrough. It would be expected that premature turbidity breakthrough could be prevented by using a filter aid, as

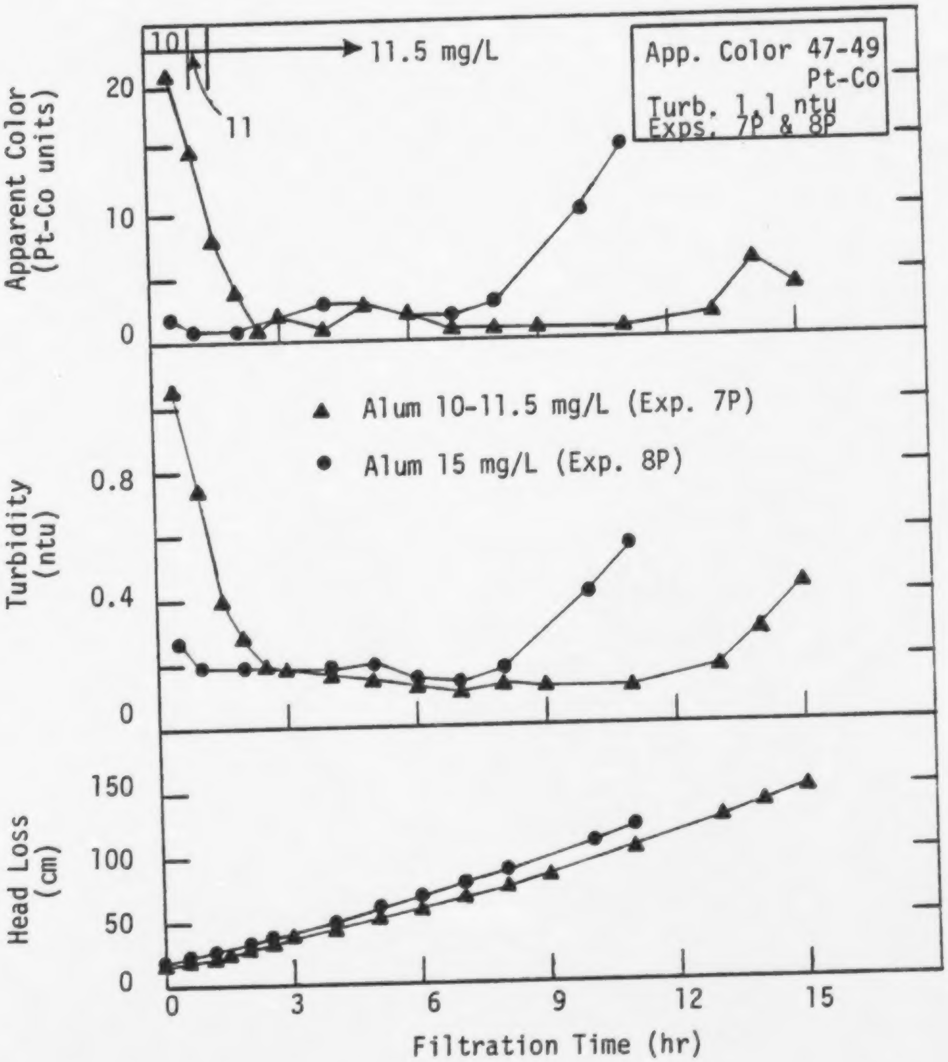

Figure 69. Waterboy filter results using alum at different pH conditions (exp. 7P raw water pH adjusted to 6.0; exp. 8P no adjustment of raw water pH (6.9)).

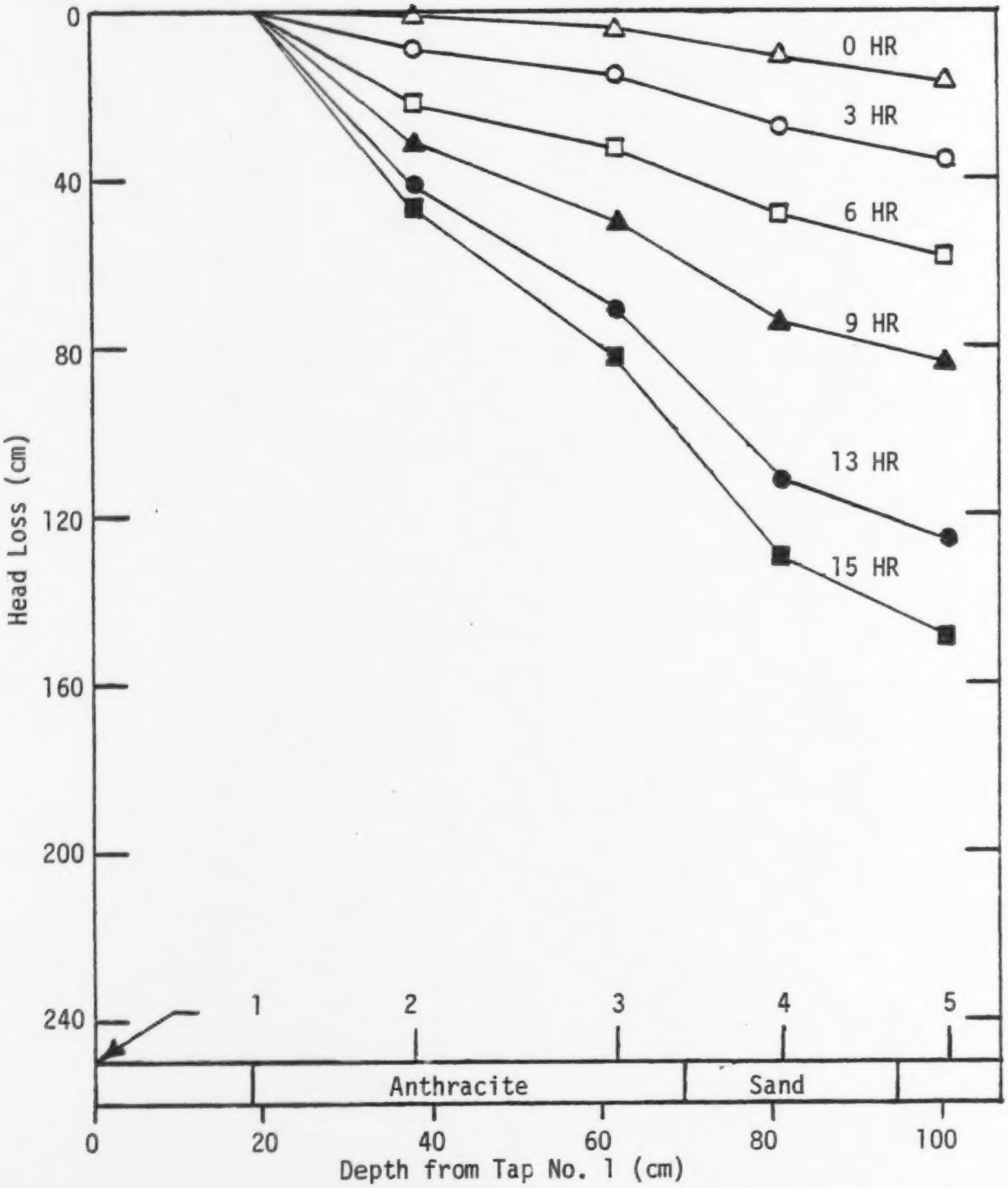

Figure 70. Head loss distributions as a function of filtration time for exp. 7P.

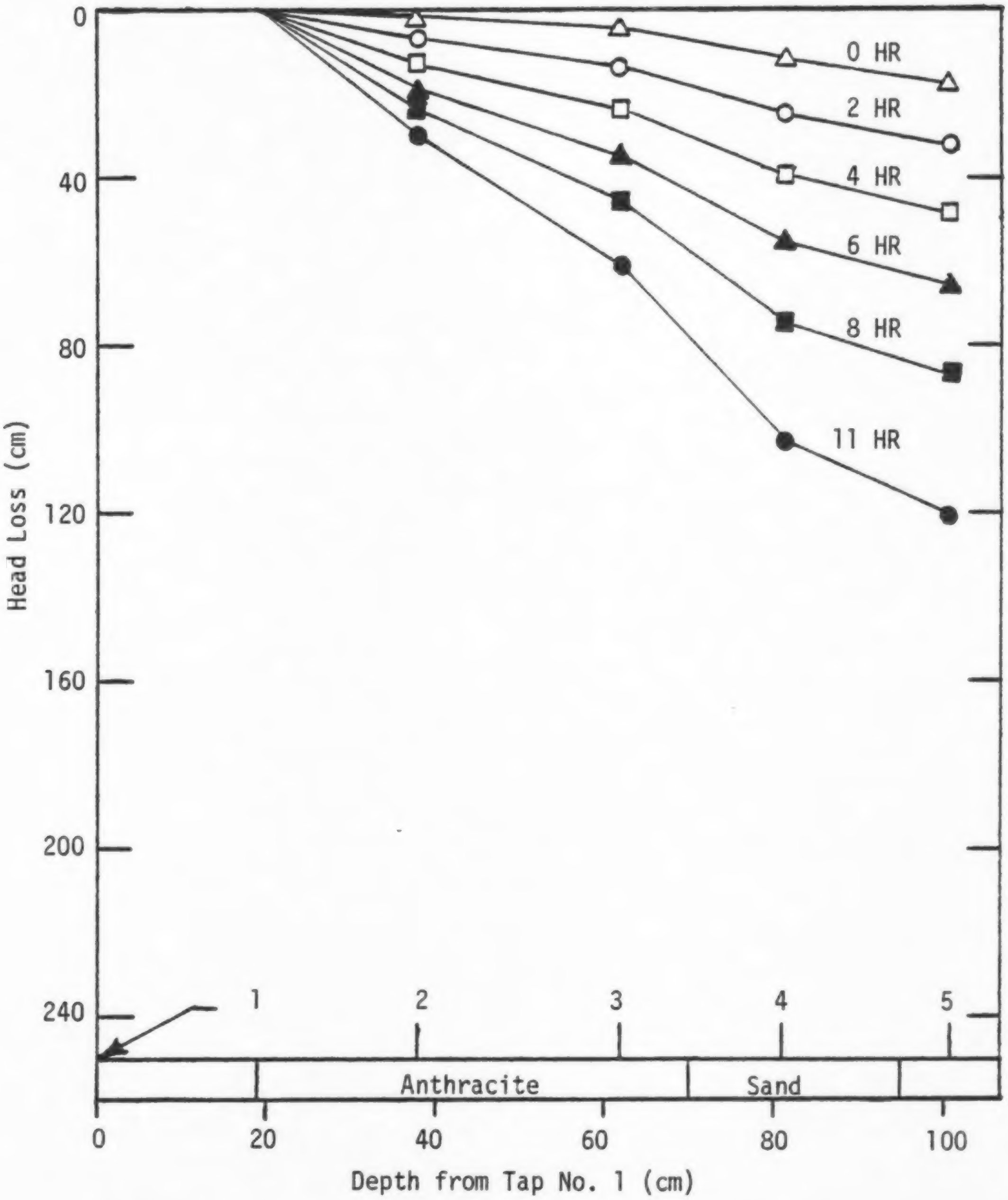

Figure 71. Head loss distributions as a function of filtration time for exp. 8P.

was the case in the small scale alum experiments and in the Waterboy polymer experiments (5P vs. 14P). However, reducing conditions in late June in the Glenmore Reservoir caused high levels of ferrous iron in the raw water and forced termination of the Waterboy experiments. If the head loss plot for experiment 7P (Figure 69) is extrapolated to 2.1 m, a filter run length of 20 hours is prediced. The corresponding net water production would be approximately 17,000 gallons.

Removal of Organics

The data on organics removals from both small scale and large scale experiments are presented here. Percent removals for apparent color, total UV (254 nm) absorbance, NPTOC, and TTHMFP are summarized. These removals are based on an average of 2 to 5 effluent grab samples collected during the course of a filter run. If adjustments were made during an experiment, such as pH or chemical dosage, no effluent TTHMFP or NPTOC samples were taken until the experiment had stabilized.

Cationic Polymers--

Three polymers were compared in small scale experiments 17A, 17B, and 18A. Magnifloc 573C (17B) was selected over Magnifloc 572C (17A) and Betz 1190 (18A) based on color and turbidity removals, as discussed previously. The organics removals summarized in Table 42 confirm the superiority of Magnifloc 573C. Removals of NPTOC and TTHMFP were 55 percent and 42 percent with Magnifloc 573C, 49 percent and 32 percent with Betz 1190, and 32 percent and 26 percent with Magnifloc 572C. Total UV and color removals were also better with Magnifloc 573C.

Effects of chemical and physical variables--Experiment 6P was performed with the Waterboy pilot plant to evaluate the effects of pH on filter performance using Magnifloc 573C. Removals of TTHMFP, apparent color, and total UV were better at pH 5.0 than at higher pH conditions as shown by the data in Table 42.

Experiment 15P was conducted to examine organics removals by Magnifloc 573C at pH 5.5 at various 573C dosages. Removal of TTHMFP was poor (25 percent) at the underdosed condition, and improved to 41 percent at the "optimum" dosage. TTHMFP removals increased to 52 percent at the slight overdose, and to 55 percent at a large overdose. These dosages of 8 and 12 mg/L are called "overdose" conditions due to the poor turbidity and apparent color data for the filtered water (see Figure 62). Total UV absorbance and NPTOC followed a similar trend. A similar phenomenon was observed for the Canton pilot plant experiments.

Experiments 5P and 14P may be compared to evaluate the effects of a filter aid on organics removal. Examination of Table 42 reveals that removals for these two experiments are essentially equal. From this, it can be concluded that the use of a filter aid did not affect organics removals.

A similar comparison may be made between experiments 4P and 5P to determine if flocculation affected organics removals. Again, removals for

TABLE 42. SUMMARY OF ORGANICS REMOVALS BY DIRECT FILTRATION USING POLYMERS (ONEIDA, N.Y.)

Exp. No.	Polymer	Dosage (mg/L)	Filt. Rate (m/hr)	Filt. Mode	pH	Percent Removal			
						App. Color	Total UV	NPTOC	TTHMFP
17A	572C	8	4.88	In-Line	5.9	66	46	32	26
17B	573C	6	4.88	In-Line	5.9	86	68	55	42
18A	1190	6	4.88	In-Line	5.9	66	52	49	32
20A	573C	2.5	4.88	In-Line	5.8	82	55	44	39
4P	573C	3	9.76	In-Line	5.6	82	46	31	40
5P	573C	3	9.76	Floc	5.6	81	46	26	41
6P	573C	3	9.76	In-Line	5.0	89	56	(10)*	53
		3			5.5	78	39	28	36
		3.5			6.1	67	32	18	30
		3.5			6.8	52	19	21	13
14P	573C 1160	5 0.1	9.76	Floc	5.5	81	49	33	38
15P	573C	2.5 u	9.76	In-Line	5.5	59	30	5	25
		5 o				80	49	54	41
		8 s.o.				80	57	40	52
		12 l.o.				60	57	54	55

u - underdose

o - optimum

s.o. - slight overdose

l.o. - large overdose

* Probably experimental error

these two experiments are nearly identical, indicating that flocculation did not affect organics removals.

Average removals--Examination of Table 42 reveals that organics removals by Magnifloc 573C at pH 5.5-5.9, particularly TTHMFP and apparent color, are similar for all experiments. Raw water quality had no apparent effect on removals of organics. TTHMFP removals ranged from 36 to 42 percent, for both the small and large scale experiments. Apparent color removals ranged from 78 to 86 percent. NPTOC and total UV (254 nm) removals were much more variable, ranging from 26 to 55 percent for NPTOC and 39 to 68 percent for total UV (254 nm). The fact that removals for small and large scale pilot plants are similar has important ramifications in the design of future pilot plants. These findings indicate that organics removals achieved by small pilot plants may be extrapolated to large scale pilot plants and full scale plants.

Average removals by Magnifloc 573C at the "optimum" dosage at pH 5.5-5.9 have been calculated. They are 81 percent for apparent color, 51 percent for total UV (254 nm), 39 percent for NPTOC, and 40 percent for TTHMFP.

Alum--

Removals for specific experiments are presented in Table 43. Average removals using alum at pH 5.5-6 have been calculated. They are: 85 percent for apparent color, 71 percent for total UV (254 nm), 56 percent for NPTOC, and 59 percent for TTHMFP. These removals are better than those achieved by Magnifloc 573C in direct filtration.

As was the case with the Magnifloc 573C experiments, removals by alum are similar for the small and large scale pilot plants. Again, the utility of the small scale pilot plant is demonstrated. Removals show no consistent trend with respect to raw water quality.

As was the case with the polymer experiments, examination of organics removals by alum for experiments 19A and 19B (see Table 43) reveals that the use of a filter aid did not affect removals. Also, flocculation had no apparent effect on removals. A comparison of experiments 7P and 8P reveals that removals (except NPTOC) by alum at effluent pH values of 5.8-5.9 (exp. 7P) and pH 6.6 (exp. 8P) were similar.

Comparison of these results with the performance of the full scale Oneida Water Treatment Plant will be done in Section 8.

TABLE 43. SUMMARY OF ORGANICS REMOVALS BY DIRECT FILTRATION USING ALUM (ONEIDA, N.Y.)

Exp. No.	Coagulant	Dosage (mg/L)	Filt. Rate (m/hr)	Filt. Mode	pH Eff.	Percent Removal			
						App. Color	Total UV	NPTOC	TTHMFP
15B	Alum	12 o 10 s.u.	4.88	In-Line	5.5	65 54	68 57	50 38	48 40
16B	Alum, 573C	11, 1	4.88	In-Line	5.5	78	53	56	54
18B	Alum	14.5	4.88	In-Line	5.6	76	73	74	56
19A	Alum	12	4.88	In-Line	5.7	84	78	72	70
19B	Alum, 985N	12, 0.1	4.88	In-Line	5.7	86	80	72	68
21A	Alum	10	4.88	Floc	5.8-6.0	96	74	38	44
21B	Alum, 985N	10, 0.1	4.88	Floc	5.7-5.9	100	72	23	62
7P	Alum	11.5	9.76	In-Line	5.8-5.9	97	69	48	66
8P	Alum	15	9.76	In-Line	6.6	97	68	67	64

o - optimum

s.u. - slight underdose

SECTION 8

DIRECT FILTRATION: DISCUSSION AND PRACTICAL APPLICATIONS

This section contains the following: A summary of the direct filtration studies, a comparison between direct filtration and conventional water treatment for removals of organic matter and THM precursors, and an evaluation of costs for direct filtration and conventional water treatment. In the direct filtration summary, specific discussion pertaining to the removals of organic matter and THM precursors is not presented, but reserved for the succeeding material on the comparison between conventional water treatment and direct filtration.

DIRECT FILTRATION STUDIES

Characterization of Raw Waters

Direct filtration pilot plant studies were conducted on the Grasse River at Canton, New York. The Grasse River is a low turbidity, low alkalinity, highly colored water supply typical of many naturally colored surface supplies found in New York, New England, and other regions of the United States. For the sampling period (February 1980 - March 1982) of this study, mean values for various water quality parameters are summarized in Table 44. The river contains high concentrations of organic matter and THM precursors. The mean THM precursor concentration, measured as the 7-day TTHMFP (pH 7.5, 20°C), is 576 μg/L. An important practical finding was the well-defined seasonal variation in organic matter - see Table 13 for details - and is discussed below.

The highest concentrations of organic matter and THM precursors for the Grasse River occur in the summer, particularly the late summer. Summer mean values are UV (254 nm) of 0.48 cm^{-1}, NPTOC of 9.8 mg/L, and TTHMFP of 783 μg/L. Lowest concentrations occur in the winter when the Grasse River is ice-covered with UV (254 nm) of 0.18 cm^{-1}, NPTOC of 4.2 mg/L, and TTHMFP of 309 μg/L. These parameters ranged from UV (254 nm) of 0.11 to 0.67 cm^{-1}, NPTOC of 2.7 to 14.7 mg/L, and TTHMFP of 232 to 1108 μg/L. This has practical applications for water supply utilities, consulting engineering firms, and regulatory agencies concerned with pilot plant studies or evaluations of existing water treatment plants. For rivers such as the Grasse River, the worst water quality in terms of organic matter and THM precursors occurs in the summer, and not in the fall during leaffall nor in the spring during spring snowmelt and runoff. Pilot plant studies should be conducted during the summer, particularly late summer, in order to assess performance under the highest concentrations of organic matter and to determine coagulant

TABLE 44. MEAN RAW WATER QUALITY DURING THIS STUDY

Parameter	Grasse River Canton, N.Y.	Glenmore Reservoir Oneida, N.Y.
Turbidity (ntu)	2.7	1.3
Apparent Color (Pt-Co units)	114	59
Total UV (cm^{-1})	0.35	0.16
NPTOC (mg/L)	7.5	4.2
TTHMFP (μg/L)	576	304

TABLE 45. POLYMER REQUIREMENTS FOR DIRECT FILTRATION OF GRASSE RIVER AS A FUNCTION OF RAW WATER QUALITY

Polymer Dose (mg/L)	Raw Water Total UV (cm^{-1})	Raw Water NPTOC (mg/L)	Raw Water TTHMFP (μg/L)
0.6	0.068	2	145
3	0.17	4	306
6	0.27	6	463
9	0.37	8	620
11	0.47	10	778

requirements. THM studies associated with pilot plant work or existing water treatment facilities should include a summer evaluation under the worst water quality conditions.

Pilot plant studies were also conducted on the Glenmore Reservoir at Oneida, New York. This is a protected, upland water supply with raw water characteristics typical of reservoirs. For the sampling period (February 1980 - June 1982) of this study, mean values for various water quality parameters are summarized in Table 44.

As does the Grasse River, the Glenmore Reservoir undergoes a well-defined seasonal variation in organic matter. Lowest values occur in the winter when the Glenmore Reservoir is ice-covered. Mean winter values are UV (254 nm) of 0.10 cm^{-1}, NPTOC of 2.9 mg/L, and TTHMFP of 200 μg/L. Highest values occur in the summer with mean values for UV (254 nm), NPTOC, and TTHMFP of 0.21 cm^{-1}, 6.0 mg/L, and 412 μg/L.

Although there is a well-defined seasonal variation, the Glenmore Reservoir contrasts with the Grasse River in that it contains lower contrations of organic matter and the yearly range in concentrations is less. For the Glenmore Reservoir, UV (254 nm), NPTOC, and TTHMFP ranged from 0.084 to 0.31 cm^{-1}, 2.0 to 10.6 mg/L, and 152 to 597 μg/L, respectively - see Table 15 for details. Most of the time, the NPTOC was below 8 mg/L and the TTHMFP was below 500 μg/L.

The practical applications of the seasonal variation in organic matter and THM precursors regarding water treatment and pilot plant studies have already been discussed.

Pilot Plant Performance and Small Scale vs. Large Scale

Direct filtration pilot plant experiments were conducted to examine the effects of chemical variables (pH, various polymers and alum, polymer dosages) and physical variables (filtration rate, in-line vs. flocculation, and water temperature) on filtration performance. The pilot plant results showed that cationic polymers can be used as the sole coagulant.

For the Grasse River, the raw water turbidity and apparent color ranged, during the pilot plant work, from 1 to 6 ntu and 50 to 200 Pt-Co units. Good filtration performance was achieved with filtered water turbidity and apparent color of 0.2 ntu and 5 to 10 Pt-Co units, respectively. pH (from pH 5.5 to pH 7.5), filtration rate (4.88 to 14.6 m/hr), in-line direct filtration vs. direct filtration with flocculation, and water temperature had little or no effect on filter performance based on removals of turbidity, color, and organic matter. There was a difference in head loss development between in-line direct filtration vs. direct filtration with flocculation, and this will be discussed later.

The pilot plant studies on the Glenmore Reservoir showed that cationic polymers can be used successfully to treat a low turbidity, moderately colored water such as the Glenmore Reservoir. With raw water turbidities of 0.75 to 1.5 ntu and apparent color values of 40 to 75 Pt-Co units, filtered water turbidities of less than 0.3 ntu and apparent color of 5 to 15 Pt-Co units were obtained. There was little or no effect on filter performance between in-line direct filtration and direct filtration with flocculation, based on removals of turbidity, color, and organic matter.

Direct filtration pilot plant studies were conducted on both a small scale (filter columns of 4.45 cm ID) and a large scale basis (Waterboy with a filter area of 0.372 m^2 (4 ft^2). An important practical finding was that the small scale pilot plant gave similar results to the large scale in evaluating various coagulants and coagulant dosages, filtered water turbidity and color, and removals of organic matter and THM precursors. This was true for both the Grasse River and the Glenmore Reservoir studies. This is important since small scale pilot plants are cheaper to construct and operate. Large scale pilot plants are necessary, however, to evaluate length of filter runs, head loss development, and backwashing. To evaluate filter run length the pilot filter should be deep enough to contain filter media depths equal to the desired design. The pilot plant should also measure head loss at several points across the bed, and it should be large enough to adequately evaluate backwashing needs.

Polymer Dosage Selection

This study demonstrated that jar tests can be used to select cationic polymer dosages for direct filtration. Figures 28 and 34 for the Grasse River and Figure 62 for the Glenmore Reservoir compare jar test results with pilot plant direct filtration results. These results show that the "optimum" dose for coagulation based on the jar tests is also a proper dose for direct filtration. They also show that underdosing and overdosing can occur in direct filtration, and can be predicted from the jar tests.

For the Glenmore Reservoir, the data base was too limited to develop a regression equation between the cationic polymer dose (required for direct filtration) and either raw water apparnet color or total UV (254 nm) absorbance. However, there was a seasonal variation in polymer dosages. In the winter and early spring when raw water quality is good (low apparent color and low concentrations of organic matter), cationic polymer (Magnifloc 573C) dosages were low and about 2 mg/L or less. During the late summer and early fall when the concentrations of organic matter are relatively high, polymer dosages were about 4 to 6 mg/L. For the average annual raw water quality conditions for Glenmore Reservoir of 0.16 cm^{-1} total UV (254 nm) absorbance, apparent color of 59 Pt-Co units, and turbidity of 1.3 ntu, the average annual polymer dosage is estimated at 4 mg/L. This polymer dosage is used in the cost analyses for the Glenmore Reservoir presented later.

For the Grasse River, regression equations were developed between the cationic polymer (Magnifloc 573C) dose and both apparent color and total UV (254 nm) absorbance. The data and regressions were previously shown in Figures 35 and 36. The polymer dose-UV regression equation has been used to estimate polymer dosages as a funciton of raw water quality. These predictions are summarized in Table 45. This table also shows raw water NPTOC and TTHMFP concentrations. These latter concentrations were calculated from the UV (254 nm) values using the regression equations for these parameters developed in Section 9.

In the winter and spring when the raw water quality of the Grasse River is good (low concentrations of organic matter), polymer (Magnifloc 573C) dosages are 3 to 4 mg/L. In the summer when UV (254 nm) and TOC are high, polymer dosages of 9 to 12 mg/L are needed. The estimated annual polymer dosage, based on average annual raw water quality (Table 44), is 8 mg/L. This dosage is used in the cost calculations for the Grasse River presented later.

The Grasse River results are highly significant and practical. They show that UV can be used as an operating parameter to choose polymer dosages. In practice, a water utility could make on-line spectrophotometric UV measurements of the raw water quality. From a predictive equation relating polymer dose to raw water UV (254 nm), the utility could then select the polymer dosage. The predictive equation developed here is specific to the Grasse River, but the principle is generally applicable. Although not investigated in this research, alum dosages needed to coagulate colored waters in conventional water treatment practice can probably also be correlated with the concentration of organic matter measured by either apparent color or UV (254 nm). Conventional water plants could monitor raw water UV (254 nm) absorbance, and use the data to choose alum dosages.

In-line vs. Flocculation

As previously mentioned, there was no difference in the removals of organic matter, nor in filtered water turbidity and color between in-line direct filtration and direct filtration with a flocculation period provided by a flocculation basin. For the Grasse River, in particular, there was substantially less head loss development when treating the same water by direct filtration with flocculation compared to in-line direct filtration. These results are significant and have design ramifications.

In the treatment of a water like the Grasse River, direct filtration with flocculation will give longer filter runs. This is explained by considering that a water with high amounts of humic matter contains high concentrations of sub-micron particles (the humic particles). By providing a flocculation period, either by use of a flocculation basin or otherwise, the humic particles can aggregate to larger sizes. The flocculation period reduces the number of particles and surface area of the particles retained in the filter by increasing the size of the particles through flocculation. This results in lower head loss development and longer filter runs. The length of the flocculation period would depend on the raw water humic concentration and water temperature. Based on the results of this study, a flocculation basin detention time of 10 minutes during summer water quality conditions was adquate. In the winter, raw water quality may be better, but the kinetics of particle collisions among particles by Brownian motion is slower so a longer flocculation period might be needed. For treating waters containing sub-micron particles, a flocculation period is recommended in all cases since it will lengthen filter runs. The flocculation tank also provides the water plant operator some time to adjust chemical (coagulant) dosages for direct filtration. A flocculation period of 20 minutes is recommended and is used in the succeeding cost analyses.

As stated above, a flocculation period can only benefit performance by reducing the head loss and increasing the length of filter runs. This would be true as long as the particles are not aggregated to a size large enough to blind the surface of the filters. For dual media filters commonly used in practice, surface blinding will probably occur with particles above 30-40 μm. This means that the flocculation period should not produce large flocs, but simply aggregate sub-micron particles to sizes of several microns and perhaps, up to 10 to 20 μm - which some people in the field call pin point floc.

The head loss distribution data collected in this study also suggests that design engineers should, in addition to the use of a flocculation period, consider larger filter media and deeper beds. All of these considerations should be incorporated into the pilot plant studies used for design.

REMOVALS OF ORGANIC MATTER BY CONVENTIONAL TREATMENT AND DIRECT FILTRATION

Average Removals

Average percent removals of organic matter and THM precursors for conventional water treatment, direct filtration using Magnifloc 573C, and direct filtration with alum are summarized in Table 46A for the Grasse River and Table 46B for the Glenmore Reservoir. The conventional water treatment plant performance data for the Grasse River at Canton, N.Y. were taken from Table 16 in Section 6. Pilot plant data presented in Tables36 and 37 (Section 7) for the Grasse River were used to summarize direct filtration performance. For the Glenmore Reservoir at Oneida, N.Y. the performance data were taken from Table 22 (Section 6) for the conventional water treatment plant and Tables 42 and 43 (Section 7) for direct filtration.

The data in Tables 46A and 46B show that the conventional water treatment plants, which use alum as a primary coagulant, yield higher removals of organic matter and THM precursors (Term TTHMs) than direct filtration. For example, average THM precursor removals were 68-72 percent by conventional treatment, 41-42 percent by direct filtration with polymer, and 59 percent by direct filtration with alum. It is interesting that for each method of treatment, the removals of organic matter and THM precursors are approximately the same for both the Grasse River and Glenmore Reservoir.

Discussion

Direct filtration with alum produced nearly 60 percent removal of THM precursors, much better than direct filtration with the cationic polymer. The use of alum in direct filtration is not recommended because of shorter filter runs. Even under well controlled conditions of pH and applied alum dosages, some precipitation of aluminum hydroxide occurs resulting in higher suspended solids loads being applied to the filter and reduced filter run times. For waters which contain high THM precursor concentrations and where

TABLE 46A. AVERAGE ORGANICS REMOVALS BY CONVENTIONAL TREATMENT AND DIRECT FILTRATION (GRASSE RIVER, CANTON, N.Y.)

Parameter	Conv. Treat. (n=16)	DF Polymer* (n=18)	DF Alum (n=7)
Total UV	80	58	76
NPTOC	69	37	57
TTHMFP+	72	42	59

TABLE 46B. AVERAGE ORGANICS REMOVALS BY CONVENTIONAL TREATMENT AND DIRECT FILTRATION (GLENMORE RESERVOIR, ONEIDA, N.Y.)

Parameter	Conv. Treat. (n=12)	DF Polymer* (n=8)	DF Alum (n=9)
Total UV	82	51	71
NPTOC	71	39	56
TTHMFP+	68	41	59

* 573C

+ Term TTHMs for conventional treatment high removals of these precursors is a treatment objective, then conventional water treatment with alum is recommended over direct filtration. This study showed that about a 70 percent reduction in precursors can be obtained when plants are operated properly, and when treating raw waters with characteristics similar to those of this study. The remaining discussion will focus on the application of direct filtration using cationic polymers as the sole coagulant. What will be addressed is the question, what raw water THM precursor concentration can be treated by direct filtration in light of the primary standard for THMs of 0.10 mg/L?

First, it should be understood that the standard for THMs is not on the precursor concentration (measured here as 7-day TTHMFPs or Term TTHMs at pH 7.5, 20°C), but applies to the Inst TTHM concentration of the finished water. THM formation through a treatment plant and therefore the Inst TTHM concentration of the finished water depends on many factors including precursor concentration of the raw water, precursor removal by the plant, chlorination practice, pH, and water temperature. Let us use the Canton water treatment plant data to illustrate some important points. For the Grasse River, the mean raw water THM precursor concentration (7-day TTHMFP) is 576 μg/L (Table 44). Using 72 percent precursor removal by conventional treatment, the precursor concentration of the finished water would be about 155 μg/L. We can not directly apply this number to the standard. All we can say is that the finished water has a potential to form 155 μg/L if chlorinated with excess chlorine and held seven days at pH 7.5. The actual measured Inst TTHM concentration of the finished water (water being pumped from the clearwell to the distribution system) for Canton was 37 μg/L - average value for 16 monitorings over a two year period. This is extremely low considering the high precursor concentration of the raw water.

There is no standard or criterion for the THM precursor concentration of a finished water. Based on the preceding discussion, let us assume, somewhat conservatively, that a finished water TTHMFP concentration of 200 μg/L is our criterion for an acceptable water. With a 42 percent reduction in THM precursors by direct filtration, we could use direct filtration with cationic polymers as the sole coagulants on raw waters with TTHMFPs up to 350 μg/L. Using the raw water regression equations developed in Section 9 which relate UV (254 nm) to TTHMFP and to NPTOC, direct filtration using cationic polymers could be used to treat raw waters with the following quality: 7-day TTHMFP of 350 μg/L, NPTOC of 4.6 mg/L and UV (254 nm) of 0.2 cm^{-1}.

In practice, direct filtration performance regarding removals of THM precursors and meeting the THM standard must be evaluated by pilot plant studies. There can be no substitute for the pilot plant studies. The criteria developed above can be used, however, as a guideline for determining the feasibility and applicability of direct filtration with cationic polymers. According to this guideline, if the average raw water quality does not exceed 0.2 cm^{-1} for UV (254 nm), 4.6 mg/L for NPTOC, and 350 μg/L for 7-day TTHMFP (pH 7.5, 20°C), direct filtration should be considered in pilot plant studies. For a direct filtration facility being used on a raw water with a large seasonal variation in THM precursor concentrations, they could use cationic polymers during the time of the year when the precursor concentration is low, and use alum for short periods when the precursor concentration is high.

COST EVALUATION OF DIRECT FILTRATION

Basis for Cost Caculations

Cost estimates were prepared to compare direct filtration and conventional water treatment. These cost estimates were prepared for both sites - the Grasse River at Canton, N.Y. and the Glenmore Reservoir at Oneida, N.Y. The costs were prepared for 5 MGD (18.9 ML/d) treatment facilities operating at 60 percent capacity.

The EPA cost curves (Gumerman *et al.*, 1979) were used to estimate most costs. Chemical costs were obtained from water plant records at Canton and Oneida and from manufacturers' quotes. All costs are presented in January 1982 dollars. Appendix C contains details of the cost estimates and unit chemical costs.

The design criteria for conventional and direct filtration facilities for Canton are presented in Table 47. The conventional water plant is similar to that currently being used to treat the Grasse River. Differences are dual media filters (Canton uses mixed media), a ground-level steel clearwell (Canton uses a below-ground concrete basin, and sludge lagoons (Canton discharges sludge and backwash water to the municipal sewer system). Chemical treatment practice and dosages are based on current operation: Alum for coagulation, nonionic polymer as a coagulant aid, soda ash for pH control, zinc polyphosphate for corrosion control, and chlorine for disinfection.

For the direct filtration facility, the following is noted. An in-line static mixer is used for mixing the cationic polymer. A flocculation tank is recommended, based on the results of this research, with a design detention period of 20 minutes. The average cationic polymer dosage (Magnifloc 573C) is estimated at 8 mg/L as previously discussed in this Section. This is used as the sole coagulant based on the results of this study. It is noted that the soda ash dosage (see Table 47) is less for direct filtration than conventional treatment because with conventional treatment the alum dosages are such that additional soda ash is needed to provide alkalinity and pH control.

Design criteria for treating the Glenmore Reservoir are summarized in Table 48. The conventional system is based on the existing plant. The chemicals used include alum for coagulation, a nonionic polymer as a filter aid, sodium hydroxide for pH control, sodium silicate for corrosion control, and chlorine for disinfection. Dosages are based on current practice at the plant. The direct filtration plant is similar to Canton except for the chemicals used. Based on the results of the pilot plant studies on the Glenmore Reservoir, an average annual cationic polymer (Magnifloc 573C) dosage of 4 mg/L is used. A nonionic polymer is also used as a filter aid. As is the case for the conventional plant, sodium hydroxide and sodium silicate are used for pH adjustment and corrosion control.

TABLE 47. DESIGN CRITERIA FOR COST ESTIMATES FOR A 5 MGD (18.9 ML/d) FACILITY AT CANTON, N.Y. (60 PERCENT OPERATING CAPACITY)

Unit Process	Conventional Treatment	Direct Filtration
Rapid Mix		
- Type	Vertical Turbine	In-Line Static Mixer, 24"
- Detention Time	90 s	5.5 s
- G (s^{-1})	900	NA
Flocculation		
- Type	Vertical Turbine	Vertical Turbine
- Detention Time	45 min	20 min
- G (s^{-1})	20	20
Sedimentation		
- Type	Tube Settlers	NA
- Tube Area	1400 ft^2	NA
Filtration		
- Type	Dual Media	Dual Media
- Number	4	4
- Filtration Rate	12.2 m/hr(5gpm/ft^2)	12.2 m/hr
- Surface Wash	Hydraulic	Hydraulic
Backwash Pumping		
- Backwash Rate	20 gpm/ft^2	20 gpm/ft^2
Clearwell		
- Type	Ground-level, steel	Ground-level, steel
- Detention Time	2 hr	2 hr
Sludge Lagoons (Cold climate; freeze-thaw cycle, 40% solids after decanting)		
- Number	2	2
- Total Sludge Storage Capacity	4 yr	4 yr
Chlorine Feed		
- Capacity	100 lb/day	100 lb/day
- Average Dose	2 mg/L	2 mg/L
Alum Feed		
- Type	Liquid Alum	NA
- Capacity	75 lb/hr	NA
- Average Dose	40 mg/L	NA

(continued)

TABLE 47 (continued)

Unit Process	Conventional Treatment	Direct Filtration
Cationic Polymer Feed		
- Type	NA	Liquid, diluted 10:1
- Capacity	NA	335 lb/day
- Average Dose	NA	8 mg/L
Coagulant Aid (Nonionic Polymer)		
- Type	Solid, diluted to 0.25%	NA
- Capacity	25 lb/day	NA
- Average Dose	0.6 mg/L	NA
Soda Ash Feed		
- Capacity	25 lb/hr	10 lb/hr
- Average Dose	15 mg/L	5 mg/L
Zinc Polyphosphate		
- Capacity	50 lb/day	50 lb/day
- Average Dose	1.5 mg/L	1.5 mg/L

TABLE 48. DESIGN CRITERIA FOR COST ESTIMATES FOR A 5 MGD (18.9 ML/d) FACILITY AT ONEIDA, N.Y. (60 PERCENT OPERATING CAPACITY)

Unit Process	Conventional Treatment	Direct Filtration
Rapid Mix		
- Type	Vertical Turbine	In-Line Static Mixer, 24"
- Detention Time	90 s	5.5 s
- $G(s^{-1})$	900	NA
Flocculation		
- Type	Vertical Turbine	Vertical Turbine
- Detention Time	45 min	20 min
- $G(s^{-1})$	20	20
Sedimentation		
- Type	Rectangular Clarifiers	NA
- Detention Time	4 hr	NA
Filtration		
- Type	Dual Media	Dual Media
- Number	4	4
- Filtration Rate	12.2 m/hr(5gpm/ft^2)	12.2 m/hr
- Surface Wash	Hydraulic	Hydraulic
Backwash Pumping		
- Backwash Rate	20 gpm/ft^2	20 gpm/ft^2
Clearwell		
- Type	Ground-level, steel	Ground-level, steel
- Detention Time	2 hr	2 hr
Sludge Lagoons (Cold climate; freeze-thaw cycle, 40% solids after decanting)		
- Number	2	2
- Total Sludge Storage Capacity	4 yr	4 yr
Chlorine Feed		
- Capacity	167 lb/day	167 lb/day
- Average Dose	4 mg/L	4 mg/L
Alum Feed		
- Type	Liquid Alum	NA
- Capacity	50 lb/hr	NA
- Average Dose	25 mg/L	NA

(continued)

TABLE 48 (continued)

Unit Process	Conventional Treatment	Direct Filtration
Cationic Polymer Feed		
- Type	NA	Liquid, diluted 10:1
- Capacity	NA	200 lb/day
- Average Dose	NA	4 mg/L
Filter Aid (Nonionic Polymer)	Solid, diluted to 0.25%	Solid, diluted to 0.25%
- Capacity	5 lb/day	5 lb/day
- Average Dose	0.1 mg/L	0.1 mg/L
Sodium Hydroxide Feed		
- Type	Liquid, 50% NaOH	Liquid, 50% NaOH
- Capacity	375 lb/day	200 lb/day
- Average Dose	9 mg/L	4.5 mg/L
Sodium Silicate Feed		
- Type	Liquid	Liquid
- Capacity	1250 lb/day	1250 lb/day
- Average Dose	30 mg/L	30 mg/L

Finally, the following points should be noted. A major difference between the two conventional water plants is the sedimentation process - tube settlers for Canton and conventional settling basins for Oneida. Dual media filters are used for both the conventional and direct filtration plants at a design filtration rate of 5 gpm/ft^2 (12.2 m/hr). Thus, the conventional plants are actually high rate water plants.

Cost Estimates

The cost estimates are summarized in Table 49A for the Canton (Grasse River) facilities and Table 49B for the Oneida (Glenmore Reservoir) facilities. Details supporting these estimates can be found in Appendix C.

The costs in the tables are presented in terms of annual capital costs, annual O&M costs (excluding chemicals), and annual chemical costs. Annual capital costs were computed for an interest rate of 10 percent over 20 years. Direct filtration is cheaper for both sites. For Canton, the cost is estimated at 36.1 cents per thousand gallons compared to 45.6 cents for conventional treatment. Conventional treatment at Oneida is more expensive due to the use of conventional settling basins as opposed to the tube settlers for Canton. For Oneida, the cost is estimated at 34.1 cents for direct filtration vs. 50.1 cents for conventional treatment.

Regarding capital costs, direct filtration has the following economic advantages:

- Savings due to elimination of the sedimentation process;
- Savings by replacing rapid mix coagulation tanks with in-line static mixers;
- Savings due to a smaller flocculation tank because of the smaller detention time; and
- Savings in sludge lagoon construction due to reduced sludge volume.

Regarding O&M costs (excluding chemicals), direct filtration cost savings result from the use of in-line static mixers (lower energy and maintenance costs), smaller flocculation basins (lower energy and maintenance costs), and reducedsludge volumes.

Chemical costs are higher, for the direct filtration facility at Canton, than the conventional treatment system, but only by $8150. This is a small difference considering the high cationic polymer dosage (8 mg/L) required on an annual basis to treat the highly colored Grasse River. Overall, the O&M costs (including chemicals) are less for direct filtration. If no change in the alum dosage is assumed, the chemical costs are equal for conventional treatment and direct filtration when the annual cationic polymer dosage is 6 mg/L. According to Table 45, this polymer dosage would be suitable for treating a raw water, similar to the Grasse River, with a UV (254 nm) of 0.27 cm^{-1}, NPTOC of 6 mg/L, and TTHMFP of 463 μg/L.

Chemicals costs for direct filtration at Oneida were also slightly higher than conventional treatment by $5800. This is small and is more than compensated by savings in other O&M costs. The net savings in annual O&M

TABLE 49A. COST SUMMARY FOR 5 MGD (18.9 ML/d) TREATMENT PLANT AT CANTON, N.Y. - CONVENTIONAL VS. DIRECT FILTRATION (60 PERCENT CAPACITY, JANUARY 1982 DOLLARS)

	Conventl.	Direct Filtration
Annual Capital Cost*	$264,300	$189,100
Annual O&M Cost (excludes chemicals)	157,350	119,700
Annual Chemical Cost	78,050	86,200
Total Annual Cost	499,700	395,000
Cost per 1000 gal +	0.456	0.361

TABLE 49B. COST SUMMARY FOR 5 MGD (18.9 ML/d) TREATMENT PLANT AT ONEIDA, N.Y. - CONVENTIONAL VS. DIRECT FILTRATION (60 PERCENT CAPACITY, JANUARY 1982 DOLLARS)

	Conventl.	Direct Filtration
Annual Capital Cost*	$335,000	$196,200
Annual O&M Cost (excludes chemicals)	165,300	123,700
Annual Chemical Cost	48,000	53,800
Total Annual Cost	548,300	373,700
Cost per 1000 gal+	0.501	0.341

* i = 10%, n = 20 years

+ 3 MGD (11.4 ML/d) basis

costs (including chemicals) amounts to $35,800.

SECTION 9

SURROGATE PARAMETERS

Three data bases were examined for surrogate relationships for predicting NPTOC and TTHMFP: (1) raw water, (2) raw water plus direct filtration pilot plant effluent, and (3) raw water plus effluent from the filters of the actual treatment plants. For each data base case, surrogate relationships were examined for three water systems: (1) Grasse River, (2) Glenmore Reservoir, and (3) pooling of data for Grasse River and Glenmore Reservoir. Emphasis is placed on examining total UV (254 nm) absorbance (unfiltered samples) for predicting NPTOC and TTHMFP; however, some discussion is devoted to the use of soluble UV (254 nm) absorbance (filtered samples), apparent color, and 2-hr chlorine demand. To aid the reader, Table 50 summarizes the coding used for the various parameters.

This section is organized as follows. First, a general discussion of TOC, THM precursors, and UV (254 nm) absorbance is presented in the subsection entitled, Introduction. Next, a brief description of the statistical techniques is presented. Finally, the results are presented and discussed for each data base case.

TABLE 50. CODING FOR VARIOUS PARAMETERS

NPTOC	-	Non-purgable Total Organic Carbon in mg/L
TTHMFP	-	Total Trihalomethane Formation Potential measured after 7 days at pH 7.5, 20°C in µg/L
TOTL-UV	-	Unfiltered UV absorbance at 254 nm (cm^{-1})
SOL-UV	-	Filtered (glass fiber filter) UV absorbance at 254 nm (cm^{-1})
APT-COL	-	Apparent Color measured at 420 nm (Pt-Co units)
Cl-2hr	-	2-hr Chlorine Deamnd in mg/L

INTRODUCTION

Non-purgable total organic carbon (NPTOC), total trihalomethane formation potential (TTHMFP), and UV (254 nm) absorbance were measured in this research to characterize the raw water quality of both water sources (Grasse River at Canton, N.Y. and Glenmore Reservoir at Oneida, N.Y.), to evaluate direct filtration pilot plant performance, and to determine conventional water treatment plant efficiencies for the water plants at Canton and Oneida. Some comments follow about these parameters and the need for a surrogate measurement for TOC and THM precursors.

TOC is a collective or group parameter. It is non-specific and includes the organic carbon fraction associated with THM precursors as well as non-precursors. For waters of high color (such as the Grasse River) where humic substances are a large portion of the organic matter, one would expect a relationship between TOC and THM precursors.

THM precursors are not measured directly. In this study THM precursors were measured indirectly by measuring the 7-day TTHMFP at pH 7.5 and 20°C. Sufficient chlorine was used in setting up samples so that a free chlorine residual of at least 0.5 mg/L was measured at the end of the 7-day formation reaction. For raw water and pilot plant effluent samples, no Inst TTHMs were present. For samples collected from the actual water treatment plants, both Inst TTHMs and Term TTHMs were measured. The samples for Term TTHMs were buffered at pH 7.5 and spiked with chlorine at the time of sampling (sufficient chlorine to ensure a residual after 7-days). For these samples the TTHMFP is equal to the difference between the chlorine spiked Term TTHM and the Inst TTHM. Since the 7-day TTHMFP is dependent upon pH, temperature, and presence of chlorine, it is important to control these parameters when using TTHMFPs for THM precursor measurements.

UV (254 nm) absorbance has been used as a surrogate for DOC (dissolved organic carbon). It should be especially good where the organic matter contains aromatic compounds such as humic substances. It is used in Germany, for example, as a control parameter for monitoring DOC removal in treatment plants and pilot plants (Sontheimer et al., 1978, Fuchs and Sontheimer, 1979). UV absorbance can be measured easily and rapidly and the equipment (UV absorbance spectrophotometer) is inexpensive compared to equipment required for TOC and THM measurements. The measurement can thus be used to monitor treatment plant or pilot plant performance - i.e., a treatment process control parameter. It is possible to place a spectrophotometer on-line and obtain continuous real-time measurements. Some of these points will be discussed later in this section.

UV (254 nm) absorbance is affected by pH and the presence of suspended solids. When it is used as a surrogate parameter, these should be controlled or, at least, accounted for. In this study no pH adjustment was made because most samples were at pH 6.3 to 7.5. Over this pH range, the effect on UV absorbance is small. Most of the work reported here is for UV (254 nm) absorbance on samples not filtered in the laboratory. This is justified because the raw waters (Grasse River and Glenmore Reservoir) were low in turbidity and because the pilot plant effluents (direct filtration) or treatment plant effluents (filtered water) were low in turbidity since the water had undergone deep bed filtration. Oxidants such as chlorine can alter organic molecules resulting in a lower UV absorbance without any removal of TOC and THM precursors. This is an important point which will be discussed later with the treatment plant data.

STATISTICAL TECHNIQUES

Least squares linear regression analyses were conducted utilizing the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) computer program (Statistical Analysis System, 1979). Results are expressed in the general linear form:

$$y = a + bx \tag{5}$$

Two parameters for evaluating the "goodness" of each model are presented. The first, r^2, is the coefficient of determination. This parameter describes how much of the variability in the dependent variable (y) is explained by the model - i.e., the regression equation. It ranges from 0 to 1, with the larger values generally indicating a better fit. An r^2 value of 1 would indicate a "perfect" fit, and a value of 0 indicates a completely random relationship. However, for a number of reasons, it should be noted that a larger r^2 value does not necessarily imply that the regression model will be a more accurate predictor. First, r^2 will generally increase as the range in x increases, even though the model may not be any better. Also, r^2 will increase as the number of observations increases, even if the new model is not superior to the old one (Montgomery and Peck, 1982).

A second paramter, α, relates to the significance of the regression. It represents the probability of committing what is called a Type I error which occurs if b=0. If b=0, this would imply that x has little or no value in predicting y. Thus a low probability of this occurring, and therefore a low value of α, indicates a high level of significance. In summary, a high value of r^2 and a low value of α generally indicate a good model.

RAW WATER DATA

Descriptions

The raw water data collected to characterize the raw water quality of the Grasse River and Glenmore Reservoir were evaluated for three system cases: 1) Grasse River only, 2) Glenmore Reservoir only, and 3) pooling of the data for a combined case of Grasse River plus Glenmore Reservoir. Below, brief descriptions of the Grasse River and Glenmore Reservoir are provided as background. Detailed descriptions are contained in Section 5.

The Grasse River was sampled on 57 occasions from February 1980 to March 1982. It is a water supply source for Canton, N.Y.. These data were used to characterize the raw water quality and to identify seasonal variations. The Grasse River is a low turbidity, low alkalinity, highly colored supply typical of many colored waters of New York, New England, and other regions of the U.S.. For the sampling period, the mean values were turbidity 2.7 ntu, apparent color 114 Pt-Co units, total UV (254 nm) absorbance 0.348 cm^{-1}, NPTOC 7.5 mg/L, and 7-day TTHMFP (pH 7.5, 20°C) 576 µg/L. The river undergoes a well-defined seasonal variation in organic matter with highest values occurring during late summer and lowest values in the winter when the river is ice-covered.

The Glenmore Reservoir was sampled on 44 occasions from February 1980 to June 1982. It is a protected upland water supply for Oneida, N.Y.. Characteristic of protected reservoirs, it is a low turbidity supply with relatively low concentrations of organic matter compared to the Grasse River. For the sampling period the mean values were turbidity 1.3 ntu, apparent color 59 Pt-Co units, total UV (254 nm) absorbance 0.161 cm^{-1}, NPTOC 4.2 mg/L, and 7-day TTHMFP 304 µg/L. It also experiences a seasonal variation in organic matter with highest concentrations in the summer and lowest in the winter when the reservoir is ice-covered. However, the variation is less extreme than that of the Grasse River.

Results

Emphasis was placed on examining UV (254 nm) absorbance as a surrogate of NPTOC and THM precursors. The latter was measured as the 7-day TTHMFP (pH 7.5, 20°C). Figures 72 and 73 illustrate for the Grasse River the excellent correlation between UV and these two parameters. Table 51 summarizes the predictive equations produced from the linear least squares regression analysis as well as pertinent statistical measures of how good the equations are.

UV is a good predictor for both NPTOC and TTHMFP for all three systems. UV explains more of the variability in the dependent variable for the Grasse River and combined Grasse River-Glenmore systems than for the Glenmore Reservoir. The higher r^2 values are due partly to a larger number of observations and broader range in the independent variable (total UV). On the other hand the lower r^2 values for the Glenmore Reservoir may be due to particulate carbon (algal cells) in the reservoir during certain times of the year which would not be accurately accounted for by our unfiltered UV absorbance measurements. This will be addressed later.

Discussion

It is obvious that UV absorbance is a good surrogate for predicting raw water NPTOC and TTHMFP (THM precursors) for the Grasse River and Glenmore Reservoir systems. UV absorbance can be measured easily and rapidly, and the analytical equipment is relatively inexpensive.

The predictive equations for NPTOC in Table 51 are different. For the Glenmore Reservoir, the equation shows a greater concentration of NPTOC per unit of UV. This points out that the nature of the organic matter is, in fact, different for the two water systems. For the Grasse River the organic matter is primarily humic matter that enters the river from the watershed and upstream bogs. The organic matter in Glenmore Reservoir is humic matter from the watershed and organic matter produced within the lake from biological

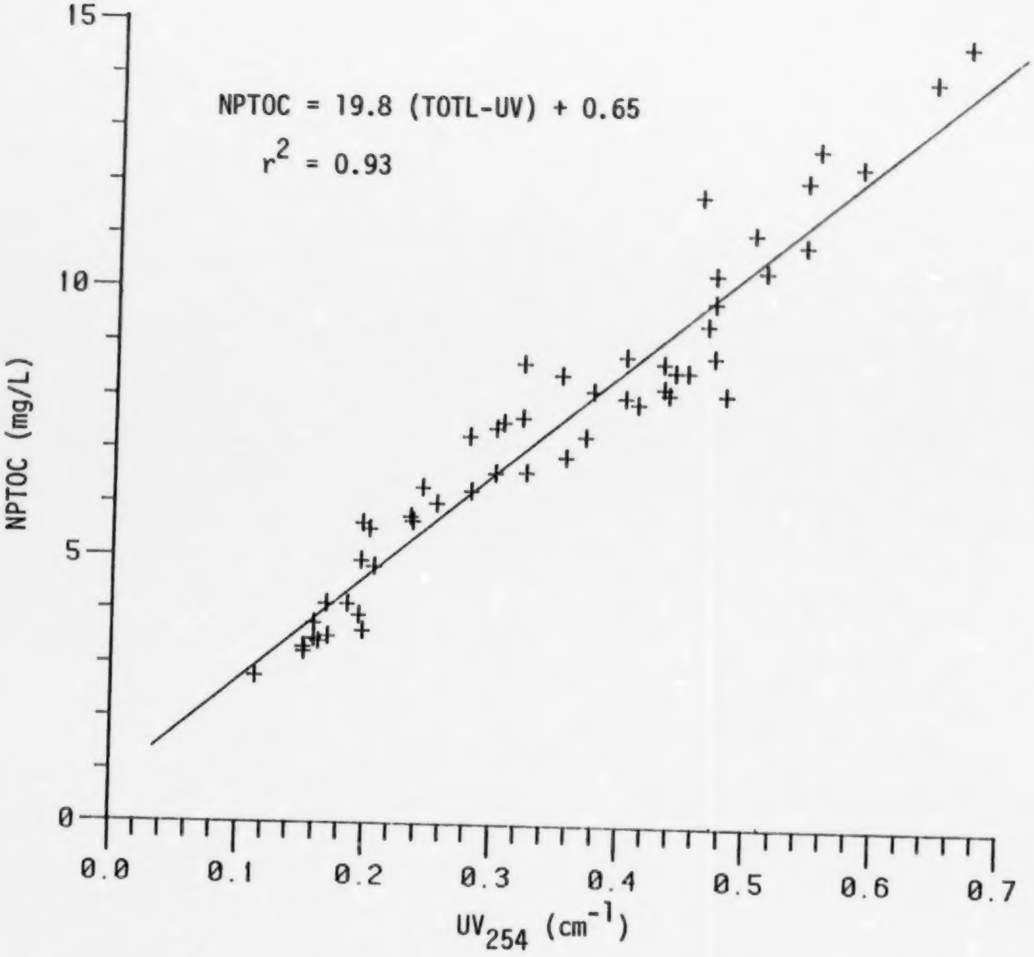

Figure 72. Correlation between total UV (254 nm) and NPTOC (Grasse River raw water).

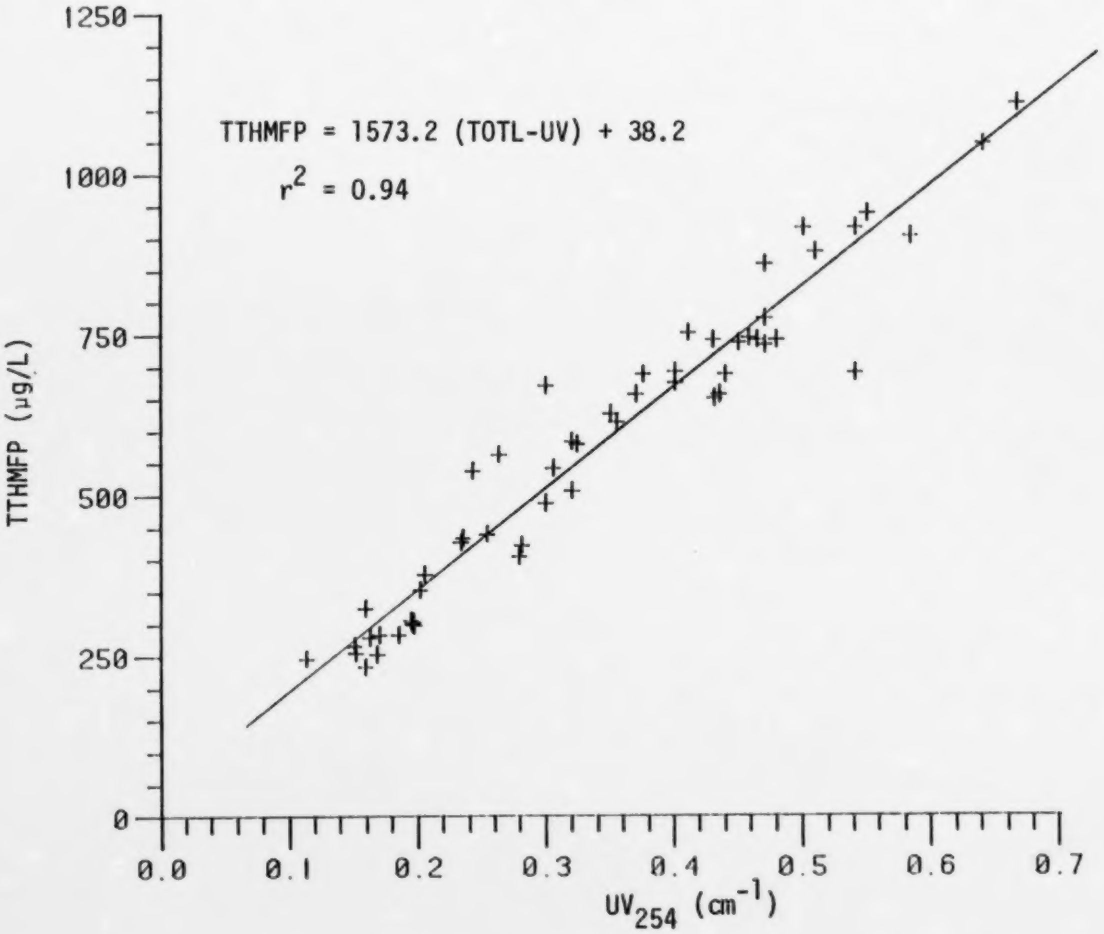

Figure 73. Correlation between total UV (254 nm) and TTHMFP (Grasse River raw water).

TABLE 51. SURROGATE EQUATIONS FROM RAW WATER DATA (DATA: FEBRUARY 1980 - JUNE 1982).

	Equation	r^2	α	n
	GRASSE RIVER RAW WATER*			
(6)	NPTOC = 19.8 (TOTL-UV) + 0.65	0.93	0.0001	53
(7)	TTHMFP = 1573.2 (TOTL-UV) + 38.2	0.94	0.0001	54
(8)	TTHMFP = 75.8 (NPTOC) + 13.6	0.91	0.0001	53
	GLENMORE RESERVOIR RAW WATER+			
(9)	NPTOC = 28.1 (TOTL-UV) - 0.3	0.71	0.0001	40
(10)	TTHMFP = 1596.1 (TOTL-UV) + 49.3	0.82	0.0001	42
(11)	TTHMFP = 45.1 (NPTOC) + 113.4	0.72	0.0001	39
	GRASSE RIVER AND GLENMORE RAW WATERS‡			
(12)	NPTOC = 19.5 (TOTL-UV) + 0.9	0.91	0.0001	93
(13)	TTHMFP = 1542.2 (TOTL-UV) + 152.8	0.95	0.0001	96
(14)	TTHMFP = 73.6 (NPTOC) + 12.9	0.90	0.0001	92

*Range in Data:

NPTOC: 2.75 - 14.7 mg/L
TOTL-UV: 0.113 - 0.666 cm^{-1}
TTHMFP: 232 - 1108 μg/L

‡Range in Data:

NPTOC: 2 - 14.7 mg/L
TOTL-UV: 0.084 - 0.666 cm^{-1}
TTHMFP: 152 - 1108 μg/L

+Range in Data:

NPTOC: 2 - 10.65 mg/L
TOTL-UV: 0.084 - 0.309 cm^{-1}
TTHMFP: 152 - 597 μg/L

activity.

Different equations would be expected for other waters due to differences in the composition of the organic matter. For example, Singer et al. (1981) show different predictive equations for UV (254 nm) for North Carolina waters. Other factors leading to different equations would be the conditions of the analytical measurements: filtered vs. unfiltered samples, pH, and conditions for determining TTHMFP. While one could argue that the equations should be site specific, the predictive equations in Table 51 developed from the Grasse River raw water data base were tested on other rivers in northern N.Y. and on a creek in central N.Y..

Samples were collected from these other waters and the UV (254 nm) absorbance values were measured. The Grasse River equations were then used to predict NPTOC and TTHMFP. These parameters were also measured analytically and the measured values compared with the predicted values in Table 52A. Using a criterion that predicted values should be within 20 percent of measured values, the predictions are excellent.

To test the Glenmore Reservoir equations on similar waters, other reservoirs or lakes should be used. Our testing of the Glenmore Reservoir equations was limited to collecting one sample each from Lake Ontario and Lake Champlain. The results in Table 52B show that these systems are not similar to the Glenmore Reservoir, although the Lake Champlain predictions are pretty good. More testing is needed on waters with characteristics more similar to the Glenmore Reservoir.

The use of the equations on other water supplies is not advocated. What is advocated is the applicability of the development and use of surrogate parameters for TOC and THM precursors. A water supply should develop its own predictive equations. UV measurements can be made continuously by use of a on-line spectrophotometer giving the water utility a record of raw water quality. The on-line measurements could also be used for control of coagulant dosages. It was shown in Section 7 and discussed in Section 8, that the optimum polymer dosage for direct filtration correlated with UV (254 nm) absorbance for the Grasse River. Therefore, a direct filtration plant treating a water like the Grasse River could monitor UV (254 nm) and choose polymer dosages from these measurements. Although not investigated in this research, alum dosages needed to coagulate colored waters in conventional treatment practice might also be correlated with UV (254 nm) absorbance.

RAW WATER AND PILOT PLANT EFFLUENT

For this data base case surrogate relationships were examined for three systems: 1) Grasse River raw water plus Canton pilot plant data, 2) Glenmore Reservoir raw water plus Oneida pilot plant data, and 3) pooling of the data for the first two systems. Direct filtration pilot plant effluent data collected for the Grasse River studies at Canton during the period of July 1980 - February 1982 were added to the raw water data base for the Grasse River. The pilot plant data include both the Waterboy and small scale direct

TABLE 52A. TESTING OF GRASSE RIVER RAW WATER SURROGATE EQUATIONS ON OTHER STREAMS

Waterbody (Location/Date)	Measured			Predicted	
	UV cm-1	NPTOC mg/L	TTHMFP µg/L	NPTOC mg/L	TTHMFP µg/L
Raquette River (Potsdam, N.Y., 9/21/81)	0.284	6.6	599	6.3	485
Raquette River (Tupper Lake, N.Y., 9/27/81)	0.312	7.6	630	6.8	529
Oswegatchie River (Gouverneur, N.Y., 11/9/81)	0.255	7.6	420	5.7*	439
Oswegatchie River (Gouverneur, N.Y., 4/19/82)	0.196	4.6	449	4.5	347*
Fish Creek (Rome, N.Y., 11/25/81)	0.172	3.5	301	4.1	309
Hudson River (North River, N.Y., 9/27/81)	0.172	3.8	394	4.1	309*
St. Lawrence River (Massena, N.Y., 11/20/81)	0.057	1.7	115	1.8	128
St. Lawrence River (Massena, N.Y., 5/3/82)	0.055	NM	130	1.7	125

TABLE 52B. TESTING OF GLENMORE RESERVOIR RAW WATER SURROGATE EQUATIONS ON OTHER LAKES

Waterbody	Measured			Predicted	
	Tot UV cm-1	NPTOC mg/L	TTHMFP µg/L	NPTOC mg/L	TTHMFP µg/L
Lake Champlain (Burlington, VT, 3/15/82)	0.108	2.1	203	2.7*	223
Lake Ontario (Oswego, N.Y., 4/21/82)	0.100	1.4	90	2.5*	209*

* Outside 20% of the measured value

filtration experiments. For Oneida the pilot plant data collected over the period of July 1980 - June 1982 were added to the raw water data for the Glenmore Reservoir. It is noted that no chlorine was used in operating the pilot plants. Therefore, no THMs were formed in the pilot plants. For raw water and pilot plant samples, TTHMFP measurements are equal to Term TTHMs.

Results

Figures 74 and 75 illustrate the association between UV (254 nm) absorbance and NPTOC and TTHMFP for the Grasse River. Table 53 summarizes the surrogate predictive equations and shows that UV is a good surrogate parameter for all three systems.

Discussion

The equations in Table 53 are slightly different from those of Table 51 because equal percent removals of UV, NPTOC, and TTHMFP are not achieved by direct filtration (see Section 7). Although the percent removals by direct filtration are not equal, the correlations developed from the pilot plant data are excellent showing that UV can be used to monitor the pilot plant.

In this research UV was used to monitor the performance of the pilot plants. This is recommended for pilot plant studies since TOC and TTHMFP measurements take time and are thus not good operating parameters for monitoring and controlling process performance. Fuchs and Sontheimer (1979) have discussed the use of UV (254 nm) absorbance as a process control parameter for monitoring dissolved organic carbon removal by granular activated carbon treatment.

It is interesting to compare the predictive equation for NPTOC developed from the Grasse River and Canton pilot plant data

$$\text{NPTOC} = 18.3\ (\text{TOTL-UV}) + 1.8 \qquad (15)$$

with an equation developed at the Norwegian Institute for Water Research (Vik, 1982)

$$\text{TOC} = 19.1\ (\text{UV}) + 2.3 \qquad (24)$$

The latter equation has a r^2 of 0.93 and was developed from data using filtered samples for raw and treated (laboratory coagulation) waters from several Norwegian lakes. These lake waters contain large amounts of humic matter. It is interesting that the equations are quite similar indicating humic waters from different areas of the world are alike in terms of UV-TOC properties. The similarity in predictive ability is illustrated next.

A water sample collected from Tjernsmotjern (lake in eastern Norway) on March 6, 1981 had a measured UV (254 nm) value of 0.65 cm^{-1} (Vik, 1962). The measured TOC was 13.1 mg/L. The Grasse River equation predicts a NPTOC of 13.7 mg/L which is actually a better prediction, for this one sample, than the prediction of 14.7 mg/L using the Norwegian equation.

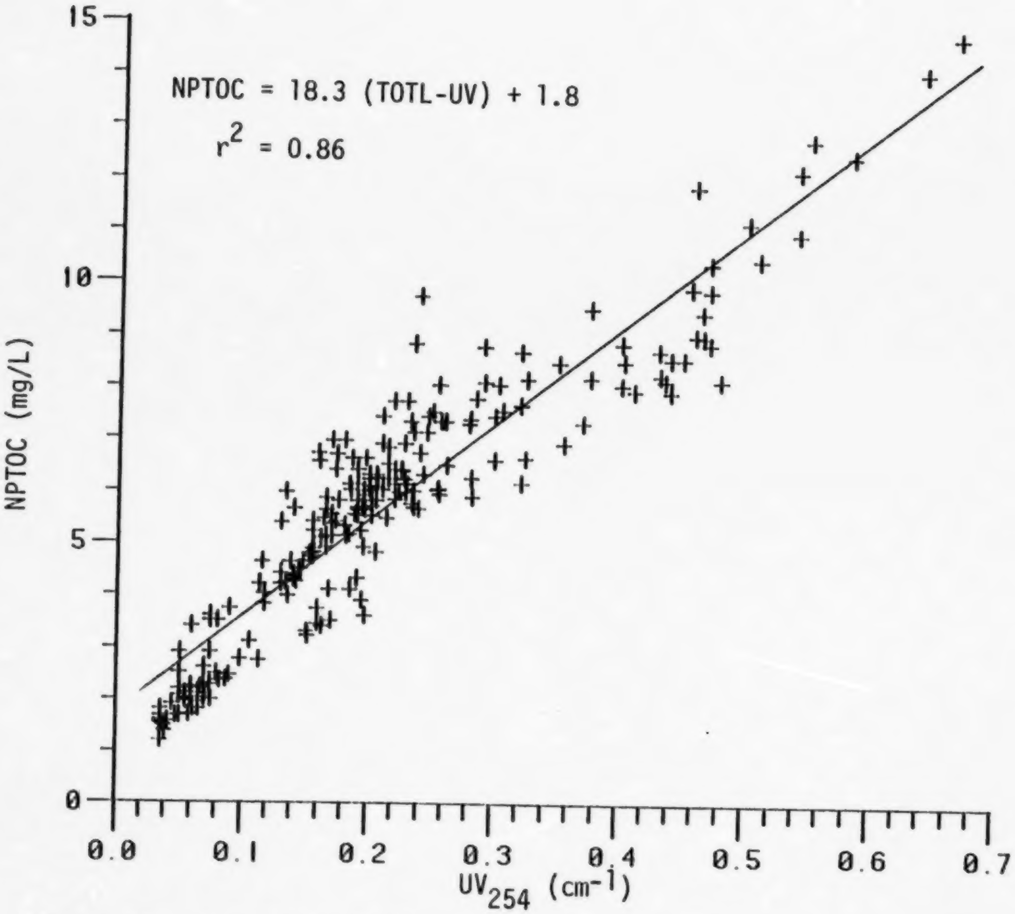

Figure 74. Correlation between total UV (254 nm) and NPTOC (Grasse River raw and Canton pilot plant effluent).

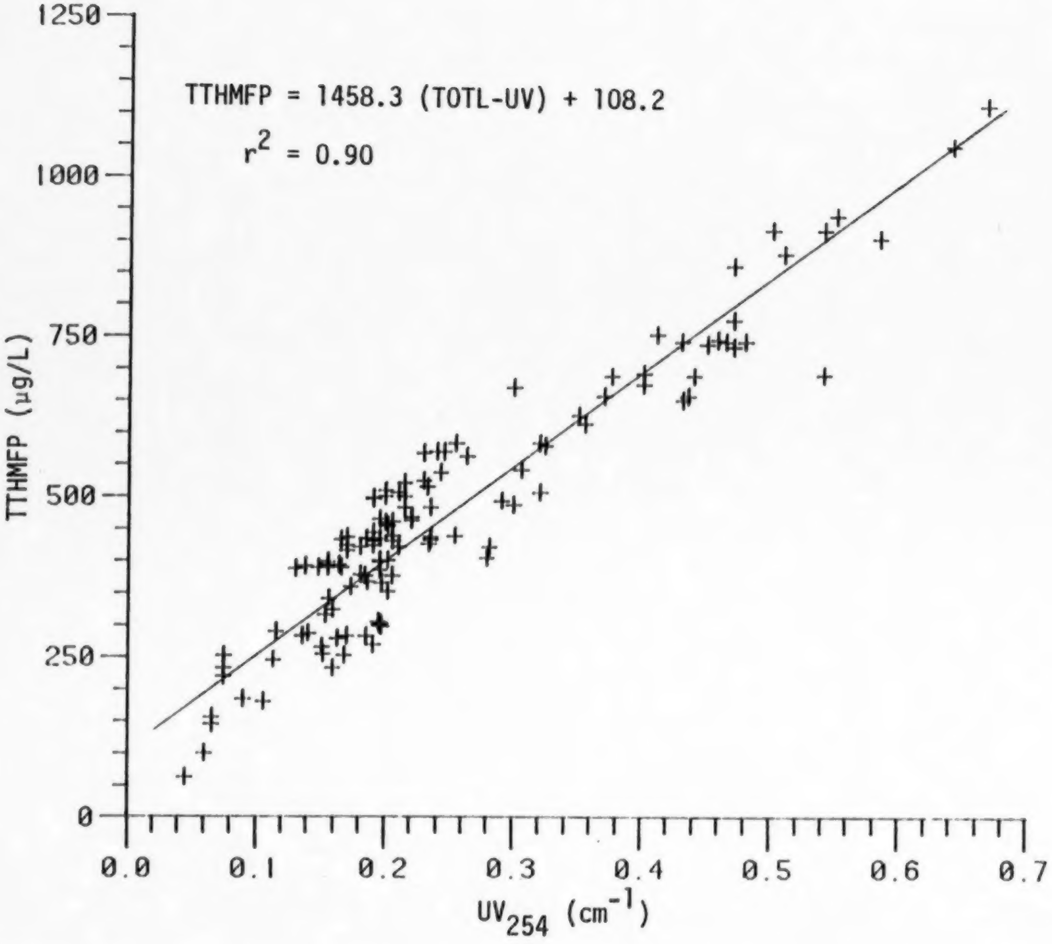

Figure 75. Correlation between total UV (254 nm) and TTHMFP (Grasse River raw and Canton pilot plant effluent).

TABLE 53. SURROGATE EQUATIONS FROM RAW WATER DATA
AND PILOT PLANT EFFLUENT DATA
(DATA: FEBRUARY 1980 - JUNE 1982)

	Equation	r^2	α	n
	GRASSE RIVER RAW WATER and CANTON PILOT PLANT*			
(15)	NPTOC = 18.3 (TOTL-UV) + 1.8	0.86	0.0001	220
(16)	TTHMFP = 1458.3 (TOTL-UV) + 108.2	0.90	0.0001	128
(17)	TTHMFP = 78.5 (NPTOC) - 23.5	0.91	0.0001	128
	GLENMORE RESERVOIR RAW WATER and ONEIDA PILOT PLANT+			
(18)	NPTOC = 21.2 (TOTL-UV) + 0.6	0.72	0.0001	177
(19)	TTHMFP = 1620.1 (TOTL-UV) + 45.4	0.89	0.0001	178
(20)	TTHMFP = 57.3 (NPTOC) + 51.6	0.73	0.0001	175
	GRASSE RIVER—GLENMORE RESERVOIR RAW WATERS and CANTON—ONEIDA PILOT PLANTS‡			
(21)	NPTOC = 20.6 (TOTL-UV) + 1.0	0.87	0.0001	405
(22)	TTHMFP = 1591.6 (TOTL-UV) + 61.0	0.93	0.0001	310
(23)	TTHMFP = 72.6 (NPTOC) + 12.0	0.92	0.0001	307

*Range in Data:
NPTOC: 2.75 - 14.7 mg/L
TOTL-UV: 0.113 - 0.666 cm^{-1}
TTHMFP: 232 - 1108 μg/L

+Range in Data:
NPTOC: 0.70 - 10.65 mg/L
TOTL-UV: 0.017 - 0.309 cm^{-1}
TTHMFP: 50 - 597 μg/L

‡Range in Data:
NPTOC: 0.70 - 14.7 mg/L
TOTL-UV: 0.017 - 0.666 cm^{-1}
TTHMFP: 50 - 1108 μg/L

The use of our pilot plant data in developing the equations in Table 53 has one disadvantage in that it includes a large number of relatively similar data values for NPTOC, UV, and TTHMFP. This can be seen by comparing Figures 74 and 75 with the other figures in Section 9.

RAW WATER AND WATER TREATMENT PLANT EFFLUENT DATA

Surrogate relationships were examined for three system cases: 1) Grasse River raw water plus Canton water treatment plant filter effluent data, 2) Glenmore Reservoir raw water plus Oneida water plant filter effluent data, and 3) pooling of these two systems. The filter effluent data were collected during the monitoring studies of the actual treatment plants in Canton and Oneida. These monitorings are described in Section 6.

The goal here was to determine whether surrogate relationships could be used to predict treatment plant performance for removals of NPTOC and THM precursors (TTHMFP). Several surrogate parameters were evaluated including total UV, soluble UV, and apparent color.

Some cautionary remarks are in order regarding surrogate parameters for actual water plants. Chlorine addition can reduce UV absorbance without removing TOC. THM precursors may be reduced, but only because part of the precursors have undergone reaction with chlorine to produce THMs. There is no real removal of THM precursors. For the Canton and Oneida water plants, while chlorine is added in a prechlorination mode (Canton) or to the top of the filters (Oneida), the doses are quite low, generally less than 2 mg/L. To avoid postchlorination problems with chlorine addition to the clearwell reducing the UV of the treated water without removing TOC and THM precursors, filter effluent data were used (sample location prior to postchlorination). These data and raw water data were used to develop predictive equations for water plant performance. The results are summarized in Tables 54-56 and discussed below.

TTHMFP vs. Total UV (254 nm)

Excellent correlation between TTHMFP and total UV (254 nm) absorbance was observed for the Glenmore Reservoir system, with an r^2 value of 0.91 (Table 55). A higher r^2 value of 0.96 was found for the Grasse River system (Table 54), and also for the combined systems (Table 56). These higher r^2 values for the Grasse River and combined systems may be partially explained by the larger number of observations and broader range in the independent variable (total UV_{254}), and they may not necessarily indicate that the latter two correlations are better predictors of TTHMFP.

Plots of TTHMFP vs. total UV absorbance for the Grasse River system and Glenmore system are shown in Figures 76 and 77. The regression equations are quite similar so that when the systems are combined, the three regression equations are virtually identical as illustrated in Figure 78.

TABLE 54. SURROGATE EQUATIONS FROM GRASSE RIVER RAW WATER DATA AND CANTON WATER FILTRATION PLANT FILTER EFFLUENT DATA (FEBRUARY 1980-MARCH 1982)

	Equation	r^2	α	n
(25)	NPTOC = 19.6 (TOTL-UV) + 0.7	0.95	0.0001	68
(26)	NPTOC = 20.6 (SOL-UV) + 0.8	0.95	0.0001	32
(27)	NPTOC = 0.73 (CL-2hr) + 1.17	0.83	0.0001	14
(28)	NPTOC = 0.05 (APT-COL) + 0.76	0.91	0.0001	36
(29)	TTHMFP = 1572.2 (TOTL-UV) + 38.9	0.96	0.0001	69
(30)	TTHMFP = 76.9 (NPTOC) - 0.6	0.94	0.0001	67
(31)	TTHMFP = 56.2 (Cl-2hr) + 115.6	0.85	0.0001	14
(32)	TTHMFP = 1635.1 (SOL-UV) + 43.8	0.97	0.0001	33
(33)	TTHMFP = 4.1 (APT-COL) + 46.7	0.91	0.0001	37

Range in Data:

TOTL-UV	0.016 - 0.666 cm^{-1}
SOL-UV	0.017 - 0.64 cm^{-1}
NPTOC	0.80 - 14.7 mg/L
CL-2hr	1.0 - 17.0 mg/L (applied chlorine 15 - 35 mg/L)
APT-COL	4 - 228 Pt-Co units
TTHMFP	69 - 1108 μg/L

TABLE 55. SURROGATE EQUATIONS FROM GLENMORE RESERVOIR RAW WATER DATA AND ONEIDA WATER TREATMENT PLANT FILTER EFFLUENT DATA (FEBRUARY 1980 - JUNE 1982)

	Equation	r^2	α	n
(34)	NPTOC = 24.1 (TOTL-UV) + 0.4	0.79	0.0001	53
(35)	NPTOC = 27.8 (SOL-UV) + 0.4	0.89	0.0001	28
(36)	NPTOC = 0.6 (CL-2hr) + 1.5	0.32	0.0363	14
(37)	NPTOC = 0.05 (APT-COL) + 1.15	0.77	0.0001	52
(38)	TTHMFP = 1602.5 (TOTL-UV) + 46.8	0.91	0.0001	58
(39)	TTHMFP = 55.8 (NPTOC) + 54.8	0.81	0.0001	52
(40)	TTHMFP = 54.4 (CL-2hr) + 52.9	0.53	0.0022	15
(41)	TTHMFP = 1746.6 (SOL-UV) + 34.1	0.93	0.0001	30
(42)	TTHMFP = 3.6 (APT-COL) + 91.5	0.89	0.0001	57

Range in Data:

NPTOC	0.21 - 10.65 mg/L
TOTL-UV	0.000 - 0.309 cm^{-1}
SOL-UV	0.001 - 0.317 cm^{-1}
CL-2hr	1.9 - 7.3 mg/L (applied chlorine 15-25 mg/L)
APT-COL	0 - 129 Pt-Co units
TTHMFP	50-597 μg/L

TABLE 56. SURROGATE EQUATIONS FROM RAW WATER DATA (GRASSE RIVER AND GLENMORE RESERVOIR) AND WATER FILTRATION PLANT FILTER EFFLUENT DATA (CANTON AND ONEIDA)

	Equation	r^2	α	n
(43)	NPTOC = 19.7 (TOTL-UV) + 0.8	0.93	0.0001	121
(44)	NPTOC = 21.7 (SOL-UV) + 0.8	0.92	0.0001	60
(45)	NPTOC = 0.72 (CL-2hr) + 1.1	0.69	0.0001	28
(46)	NPTOC = 0.05 (APT-COL) + 1.1	0.86	0.0001	88
(47)	TTHMFP = 1556.8 (TOTL-UV) + 47.5	0.96	0.0001	127
(48)	TTHMFP = 74.8 (NPTOC) + 1.9	0.93	0.0001	119
(49)	TTHMFP = 59.6 (CL-2hr) + 58.8	0.80	0.0001	29
(50)	TTHMFP = 1625.5 (SOL-UV) + 42.0	0.97	0.0001	63
(51)	TTHMFP = 3.9 (APT-COL) + 72.2	0.90	0.0001	94

Range in Data:

NPTOC	0.21 - 14.7 mg/L
TOTL-UV	0.000 - 0.666 cm^{-1}
SOL-UV	0.001 - 0.640 cm^{-1}
CL-2hr	1.0 - 17.0 mg/L (applied chlorine 15-35 mg/L)
APT-COL	0 - 288 Pt-Co units
TTHMFP	50 - 1108 μg/L

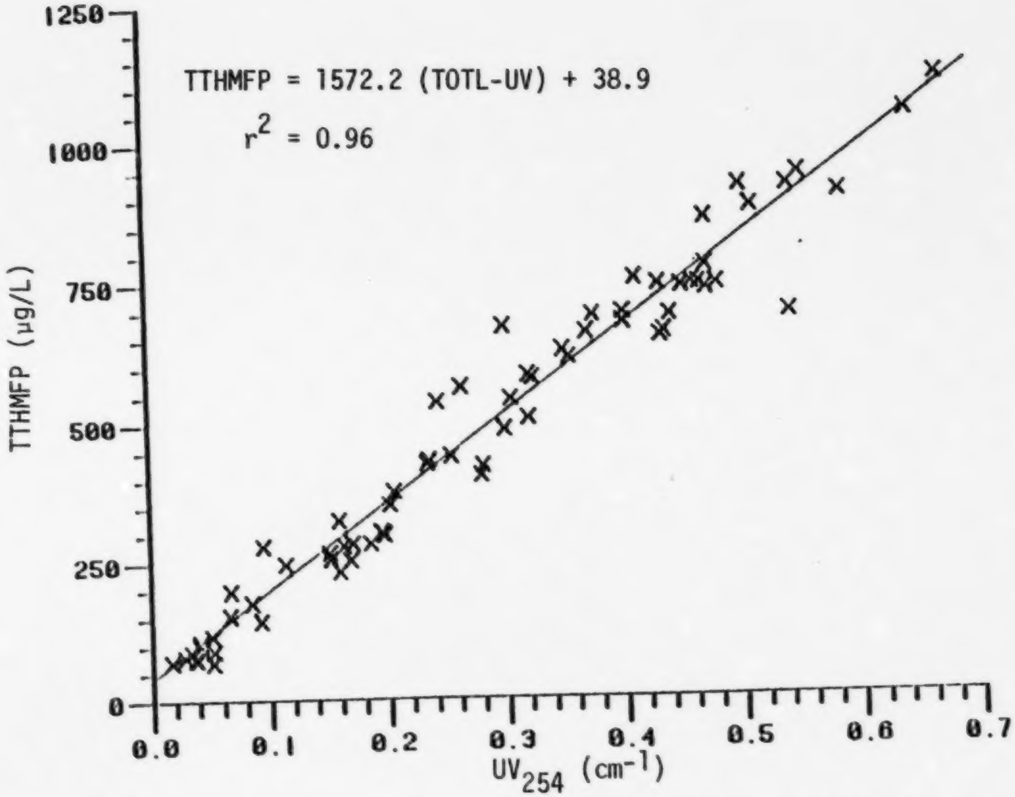

Figure 76. Correlation between total UV (254 nm) and TTHMFP (Grasse River raw water plus Canton water plant filter effluent).

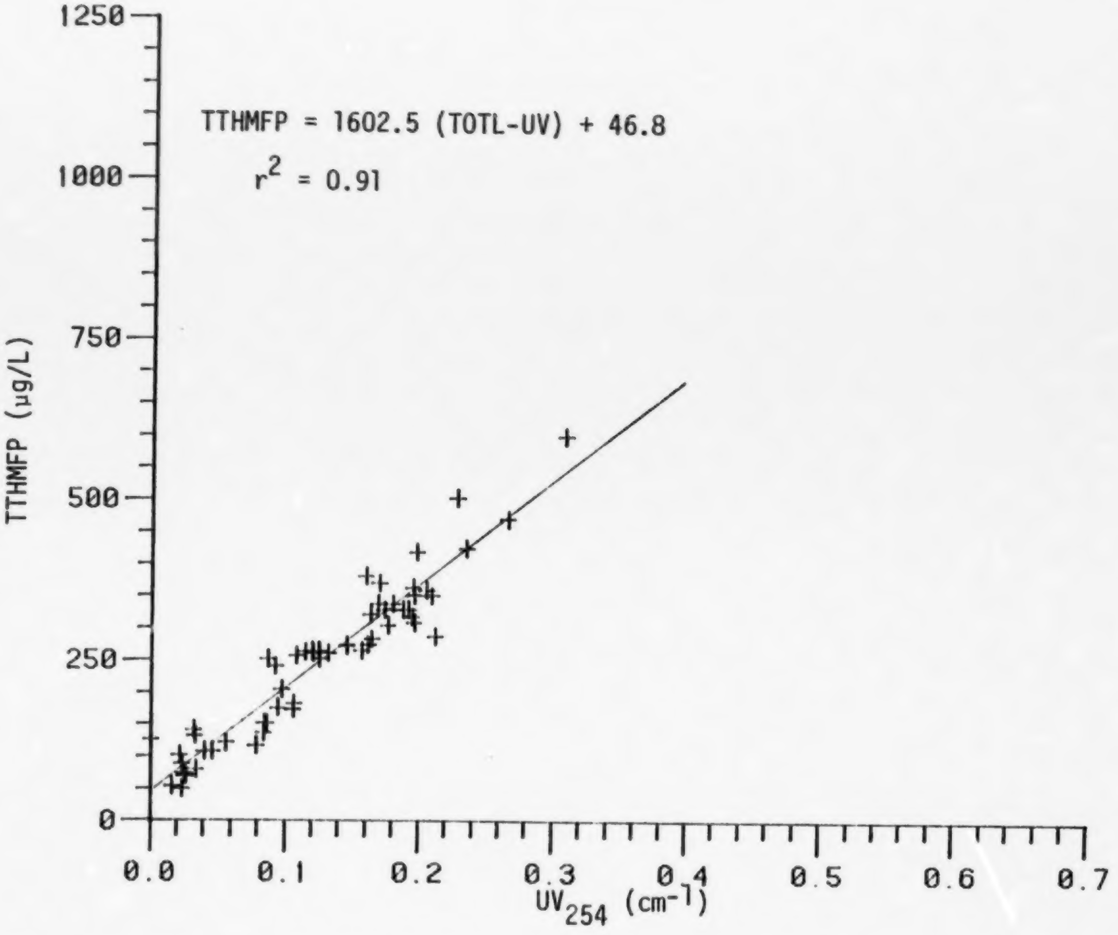

Figure 77. Corelation between total UV (254) and TTHMFP (Glenmore Reservoir raw water plus Oneida water plant filter effluent).

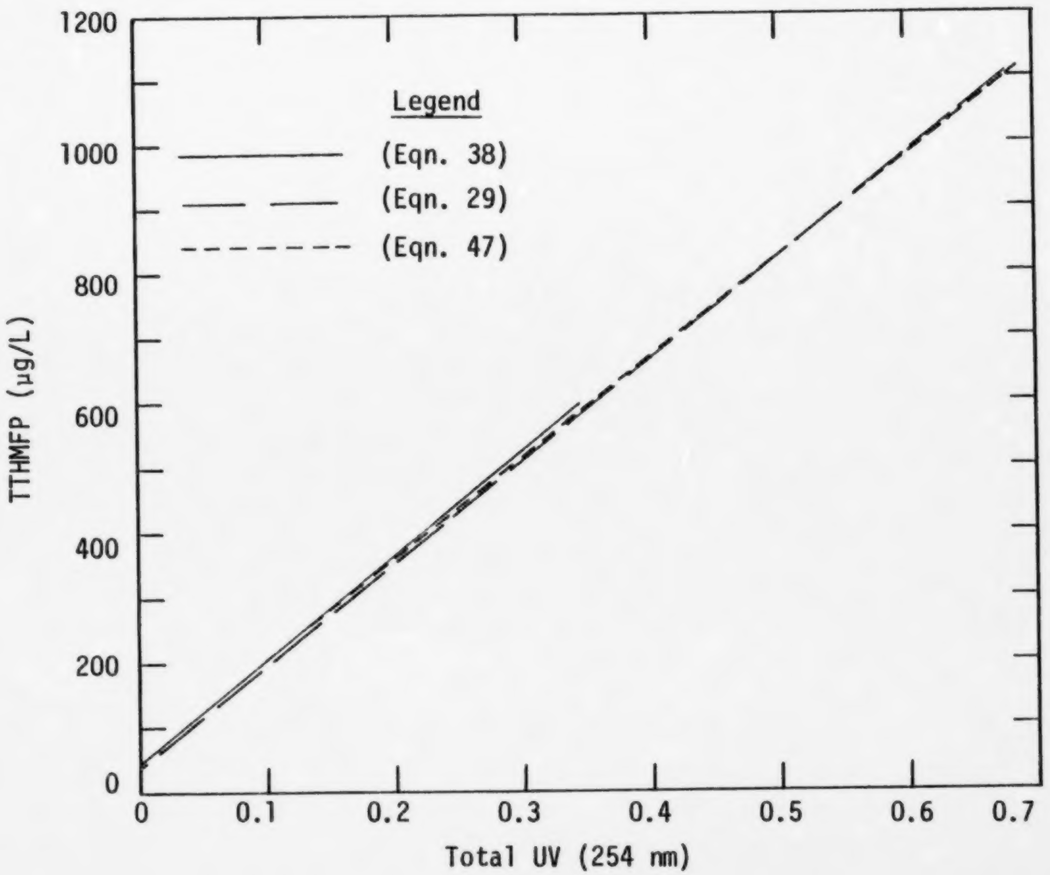

Figure 78. Comparison of TTHMFP vs. total UV regression equations.

NPTOC vs. Total UV (254 nm)

Total UV (254 nm) absorbance was also found to accurately predict the NPTOC content of raw and treated water. Plots for the Grasse River system, the Glenmore Reservoir system, and the combined systems are shown in Figures 79, 80, and 81. Values of r^2 for the Grasse River, Glenmore Reservoir, and combined systems are 0.95, 0.79, and 0.93, respectively. The lower r^2 value for the Glenmore Reservoir may be due to the presence of particulate organic carbon in the raw water. When the regression is made on filtered samples (soluble UV (254 nm) absorbance), the r^2 value improves to 0.89 (Table 55).

TTHMFP vs. NPTOC

Good correlations between NPTOC and TTHMFP were also found. Again, the r^2 value for the Glenmore Reservoir was somewhat less than for the Grasse River (0.81 vs. 0.94). The combined systems has an r^2 value of 0.93.

Additional Analyses

Correlations of NPTOC and TTHMFP versus soluble UV (254 nm) absorbance were also computed. Values of r^2 are generally equal to or slightly better than similar correlations using total UV absorbance. However, soluble UV measurements were made only during treatment plant monitorings so the number of observations is substantially less.

Apparent color was found to be a good predictor of TTHMFP for both the Glenmore Reservoir and Grasse River (r^2 values of 0.89 and 0.91, respectively). NPTOC prediction by apparent color was also good for the Grasse River ($r^2 = 0.91$), and somewhat worse for the Glenmore Reservoir ($r^2 = 0.77$).

The 2-hr chlorine demand was seen to be a good predictor of raw water NPTOC and TTHMFP for the Grasse River, with r^2 values of 0.83 for NPTOC and 0.85 for TTHMFP (see Table 54). However, poor correlations were found for the Glenmore Reservoir, with r^2 values of 0.32 for NPTOC and 0.53 for TTHMFP (see Table 55). The corresponding α values were also higher for the Glenmore Reservoir. The poor performance of 2-hr chlorine demand to predict organics levels in the reservoir may be explained by the large seasonal fluctuations in reduced metals such as Fe^{+2} and Mn^{+2} which create a substantial chlorine demand.

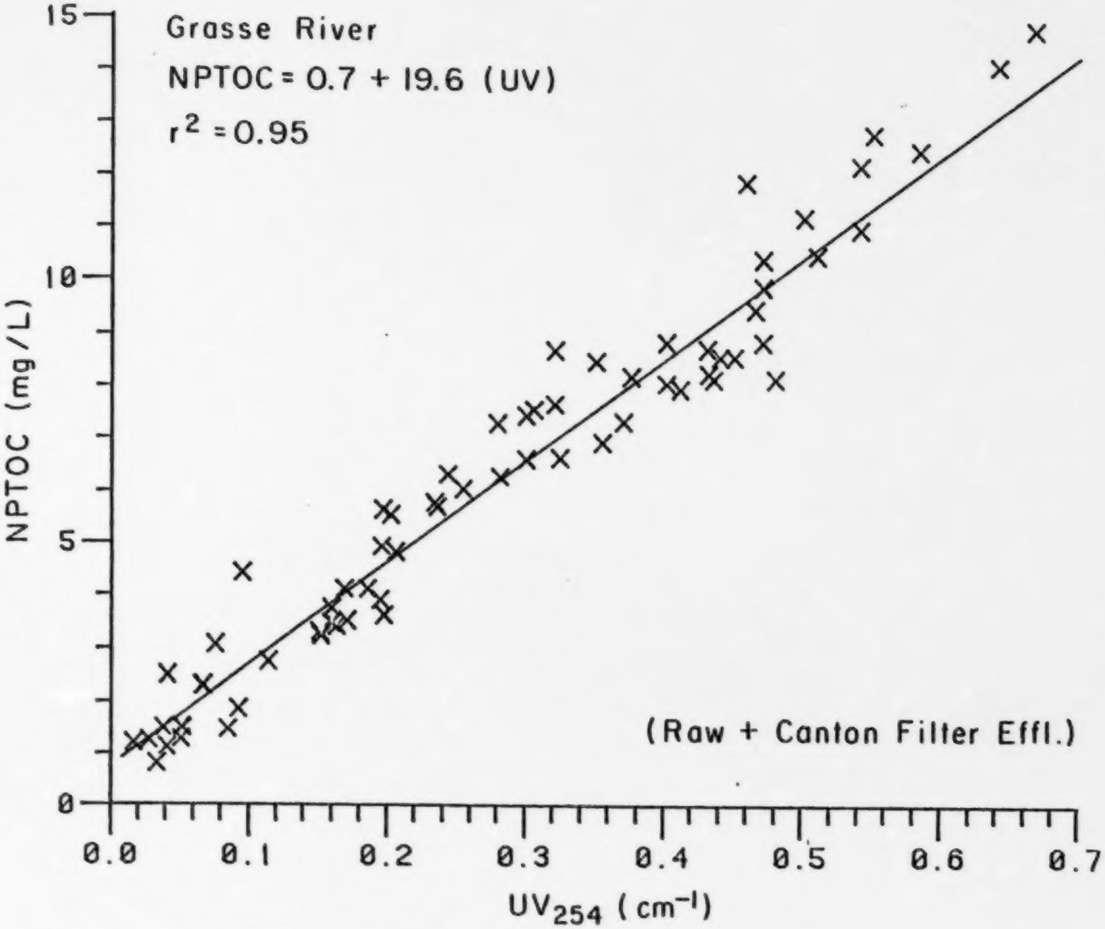

Figure 79. Correlation between total UV (254 nm) and NPTOC (Grasse River raw water plus Canton water plant filter effluent).

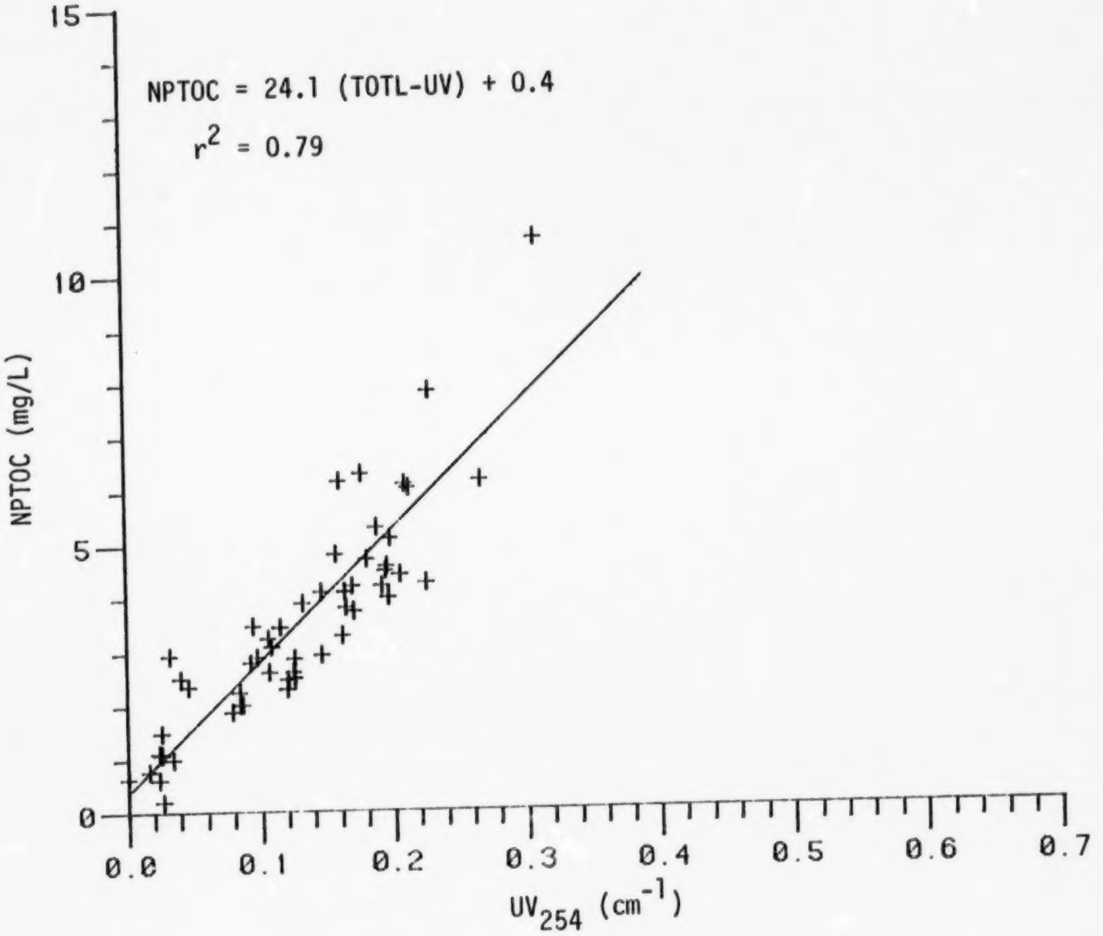

Figure 80. Correlation between total UV (254 nm) and NPTOC (Glenmore Reservoir raw water plus Oneida water plant filter effluent).

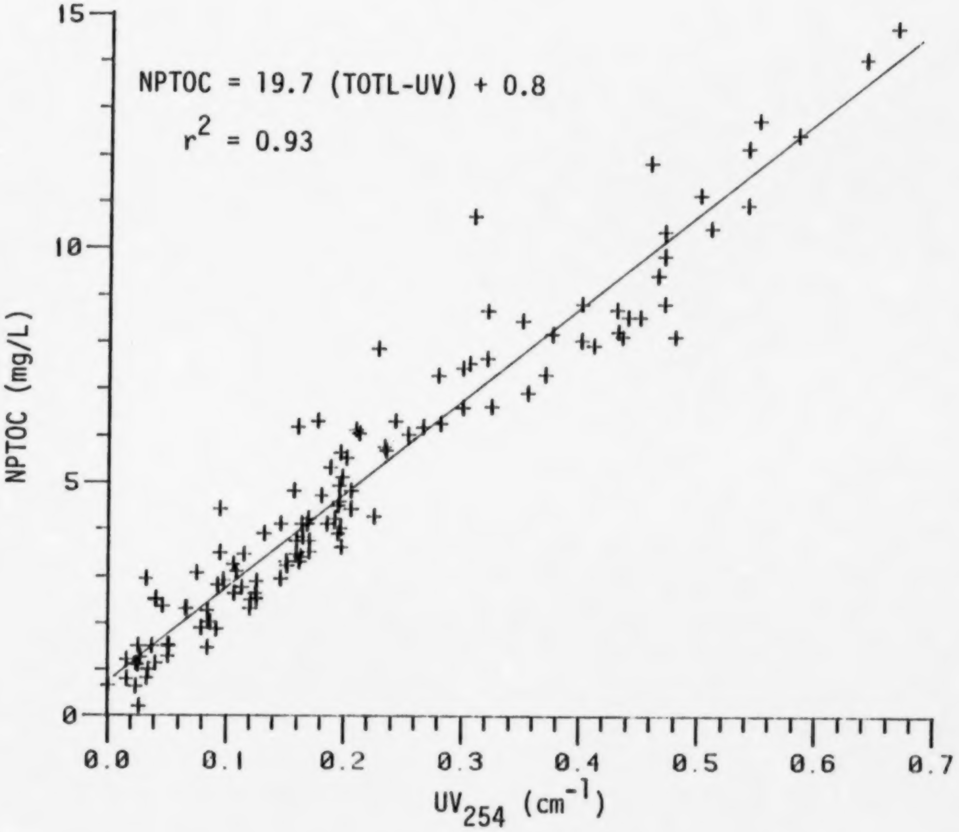

Figure 81. Correlation between total UV (254 nm) and NPTOC (Grasse River and Glenmore Reservoir raw water data plus Canton and Oneida water plants' filter effluent data).

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APPENDIX A

PROCEDURES FOR CLEANING GLASSWARE

THM AND TOC GLASSWARE

All glassware used for THM and TOC analyses required special cleaning. Screw cap vials and extraction vials were thoroughly washed in distilled water followed by rinsing with deionized water and then low organic water. The vials were then placed in an oven at 230°C for 2-4 hours. The septa were washed with deionized water, soaked and boiled in low organic water, air dried, and covered until the vials were cooled and ready to be sealed. The caps were washed and rinsed with deionized water, air dried, and then placed with clean septa on the vials. The pipets used for THM analysis were rinsed with distilled water, soaked in chromic acid and rinsed with distilled water, then deionized water, and finally low organic water. The pipets were air dried and then placed in an oven at 90°C for 2 hours. After cooling the pipets were covered with aluminum foil.

OTHER GLASSWARE

Glassware used for chlorine residual measurements was soaked in 100 mg/L chlorine solution, rinsed with chlorine demand free water and air dried. In general, routine glassware used in conjunction with pilot plant work and jar tests was initially cleaned by soaking in 1+1 HCl followed by rinsing with distilled water and deionized water. As needed, this glassware was subjected to additional HCl cleaning.

APPENDIX B

VELOCITY GRADIENT CALCULATIONS

IN-LINE STATIC MIXERS

Kirmeyer's (1979) report to EPA contains pressure drop data for the in-line static mixers used in the Waterboy pilot plant. Some of the pertinent data are summarized in Table B-1.

TABLE B-1. MIXING DATA FOR 5.1 cm STATIC MIXER (FROM KIRMEYER (1979))

Flow Rate (L/s)	Time (sec)	Head Loss (ft)	G* (sec^{-1})
0.50	1.8	0.21	502
1.01	0.92	0.85	1414
1.45	0.61	1.96	2637

* Values for 8.5°C.

These data were used to calculate velocity gradient values for the flow and temperature conditions of this study using the following equation.

$$G = \left(\frac{62.4\ h}{\mu\ \ t}\right)^{1/2} \qquad \text{(B-1)}$$

where
G = mean square velocity gradient (sec^{-1}),
h = head loss (ft),
μ = absolute fluid viscosity ($lb\text{-}sec/ft^2$)
t = time (sec).

FLOCCULATOR

Kirmeyer (1979) gives tip velocities for the Waterboy paddle flocculator in his report. These data were used to calculate velocity gradient values from equation B-2 for the Waterboy flocculation tank.

$$G = \left(\frac{C_d/2\ A\ \rho_\ell\ v^3}{\mu\ V}\right)^{1/2} \qquad \text{(B-2)}$$

where G = velocity gradient (sec)
C_d = drag coefficient = 1.8
A = area of paddles = 6039 cm^2
ρ_ℓ = fluid density (g/cm^3)
v = relative velocity of paddles in fluid (m/sec) = 0.7 times the tip velocity
μ = absolute fluid viscosity (g/cm-sec)
V = tank volume (m^3).

APPENDIX C

TABLE C-1. CAPITAL COST ESTIMATE FOR A 5 MGD (18.9 ML/d) CONVENTIONAL WATER TREATMENT PLANT AT CANTON, N.Y. (JAN. 1982 DOLLARS)

TABLE C-2. O&M COST ESTIMATE FOR A 5 MGD (18.9 ML/d) CONVENTIONAL WATER TREATMENT PLANT AT CANTON, N.Y. (60% CAPACITY, JAN. 1982 DOLLARS)

TABLE C-3. CAPITAL COST ESTIMATE FOR A 5 MGD (18.9 ML/d) DIRECT FILTRATION PLANT AT CANTON, N.Y. (JAN. 1982 DOLLARS)

TABLE C-4. O&M COST ESTIMATE FOR A 5 MGD (18.9 ML/d) DIRECT FILTRATION PLANT AT CANTON, N.Y. (60% CAPACITY, JAN. 1982 DOLLARS)

TABLE C-5. CAPITAL COST ESTIMATE FOR A 5 MGD (18.9 ML/d) CONVENTIONAL WATER TREATMENT PLANT AT ONEIDA, N.Y. (JAN. 1982 DOLLARS)

TABLE C-6. O&M COST ESTIMATE FOR A 5 MGD (18.9 ML/d) CONVENTIONAL WATER TREATMENT PLANT AT ONEIDA, N.Y. (60% CAPACITY, JAN. 1982 DOLLARS)

TABLE C-7. CAPITAL COST ESTIMATE FOR A 5 MGD (18.9 ML/d) DIRECT FILTRATION PLANT AT ONEIDA, N.Y. (JAN. 1982 DOLLARS)

TABLE C-8. O&M COST ESTIMATE FOR A 5 MGD (18.9 ML/d) DIRECT FILTRATION PLANT AT ONEIDA, N.Y. (60% CAPACITY, JAN. 1982 DOLLARS)

TABLE C-9. CHEMICAL COSTS (JAN. 1982 DOLLARS)

TABLE C-1. CAPITAL COST ESTIMATE FOR A 5 MGD (18.9 ML/d) CONVENTIONAL WATER TREATMENT PLANT AT CANTON, N.Y. (JAN. 1982 DOLLARS)

Item	Construction Cost $
Rapid Mix	37,000
Flocculation	184,000
Tube Settlers	210,000
Filtration	582,000
Backwash Pumping	85,000
Clearwell	145,000
Sludge Lagoons	118,000
Chlorine Feed	33,000
Alum Feed	41,000
Soda Ash Feed	30,000
Coagulant Aid Feed	27,000
Zn Polyphosphate Feed	16,000
Admin., Maint., and Lab. Bldg.	80,000
· Subtotal	1,588,000
Sitework @ 5%	79,000
· Total Construction Cost	1,667,000
General Contractor's OH and Profit @ 12%	200,000
· Subtotal	1,867,000
Engineering @ 10%	186,700
· Subtotal	2,053,700
Land (owned by city)	0
· Subtotal	2,053,700
Legal, Fiscal, Admin.	26,300
· Subtotal	2,080,000
Interest during Construction @ 10% rate	170,000
Total Capital Cost	2,250,000

TABLE C-2. O&M COST ESTIMATE FOR A 5 MGD (18.9 ML/d) CONVENTIONAL WATER TREATMENT PLANT AT CANTON, N.Y. (60% CAPACITY, JAN. 1982 DOLLARS)

Item	Chemical ($/yr)	Energy* ($/yr)	Maint. Matl. ($/yr)	Labor+ ($/yr)	Total ($/yr)
Rapid Mix	-	18,200	40	5,000	23,240
Flocculation	-	280	1,300	2,000	3,580
Tube Settlers	-	800	700	3,000	4,500
Filtration	-	12,350	5,500	22,000	39,850
Backwash Pumping	-	1,200	1,450	2,200	4,850
Clearwell	-	-	-	-	-
Sludge Lagoons	-	1,000	200	7,000	8,200
Chlorine Feed	2,000	1,600	2,600	5,000	11,200
Alum Feed	27,000	1,260	100	650	29,010
Soda Ash Feed	10,000	900	100	650	11,650
Coagulant Aid Feed	14,250	1,750	300	2,000	18,300
Zn Polyphosphate Feed	24,800	400	120	1,000	26,320
Admin., Maint., and Lab Bldg.	-	10,500	4,200	40,000	54,700
Totals	78,050	50,240	16,610	90,500	235,400

* $0.07 per kw-hr

+ $10 per man-hr

TABLE C-3. CAPITAL COST ESTIMATE FOR A 5 MGD (18.9 ML/d) DIRECT FILTRATION PLANT AT CANTON, N.Y. (JAN. 1982 DOLLARS)

Item	Construction Cost $
In-Line Mixer	10,000
Flocculation	118,000
Filtration	582,000
Backwash Pumping	85,000
Clearwell	145,000
Sludge Lagoons	30,000
Chlorine Feed	33,000
Cationic Polymer Feed	10,000
Soda Ash Feed	26,000
Zn Polyphosphate Feed	16,000
Admin., Maint., and Lab. Bldg.	80,000
· Subtotal	1,135,000
Sitework @ 5%	57,000
· Total Construction Cost	1,192,000
General Contractor's OH and Profit @ 12%	143,000
· Subtotal	1,335,000
Engineering @ 10%	133,500
· Subtotal	1,468,500
Land (owned by city)	0
· Subtotal	1,468,500
Legal, Fiscal, Admin.	21,500
· Subtotal	1,490,000
Interest during Construction @ 10% rate	120,000
Total Capital Cost	1,610,000

TABLE C-4. O&M COST ESTIMATE FOR A 5 MGD (18.9 ML/d) DIRECT FILTRATION PLANT AT CANTON, N.Y. (60% CAPACITY, JAN. 1982 DOLLARS)

Item	Chemical ($/yr)	Energy* ($/yr)	Maint. Matl. ($/yr)	Labor+ ($/yr)	Total ($/yr)
In-Line Mixer	-	-	-	-	-
Flocculation	-	120	870	1,500	2,490
Filtration	-	12,350	5,500	22,000	39,850
Backwash Pumping	-	1,200	1,450	2,200	4,850
Clearwell	-	-	-	-	-
Sludge Lagoons	-	210	130	1,500	1,840
Chlorine Feed	2,000	1,600	2,600	5,000	11,200
Cationic Polymer Feed	56,000	1,500	400	2,000	59,900
Soda Ash Feed	3,400	600	100	650	4,750
Zn Polyphosphate Feed	24,800	400	120	1,000	26,320
Admin., Maint., and Lab Bldg.	-	10,500	4,200	40,000	54,700
Totals	86,200	28,480	15,370	75,850	205,900

* $0.07 per kw-hr

+ $10 per man-hr

TABLE C-5. CAPITAL COST ESTIMATE FOR A 5 MGD (18.9 ML/d) CONVENTIONAL WATER TREATMENT PLANT AT ONEIDA, N.Y. (JAN. 1982 DOLLARS)

Item	Construction Cost $
Rapid Mix	37,000
Flocculation	184,000
Sedimentation	655,000
Filtration	582,000
Backwash Pumping	85,000
Clearwell	145,000
Sludge Lagoons	85,000
Chlorine Feed	40,000
Alum Feed	34,000
Filter Aid Feed	27,000
Sodium Hydroxide Feed	23,000
Sodium Silicate Feed	34,000
Admin., Maint., and Lab Bldg.	80,000
· Subtotal	2,011,000
Sitework @ 5%	101,000
· Total Construction Cost	2,112,000
General Contractor's OH and Profit @ 12%	253,000
· Subtotal	2,365,000
Engineering @ 10%	236,500
· Subtotal	2,601,500
Land (owned by city)	0
· Subtotal	2,601,500
Legal, Fiscal, Admin.	30,500
· Subtotal	2,632,000
Interest during Construction @ 10% rate	220,000
Total Capital Cost	2,852,000

TABLE C-6. O&M COST ESTIMATE FOR A 5 MGD (18.9 ML/d) CONVENTIONAL WATER TREATMENT PLANT AT ONEIDA, N.Y. (60% CAPACITY, JAN. 1982 DOLLARS)

Item	Chemical ($/yr)	Energy* ($/yr)	Maint. Matl. ($/yr)	Labor+ ($/yr)	Total ($/yr)
Rapid Mix	-	18,200	40	5,000	23,240
Flocculation	-	280	1,300	2,000	3,580
Sedimentation	-	1,120	2,900	10,000	14,020
Filtration	-	12,350	5,500	22,000	39,850
Backwash Pumping	-	1,200	1,450	2,200	4,850
Clearwell	-	-	-	-	0
Sludge Lagoons	-	600	150	4,000	4,750
Chlorine Feed	4,000	2,150	2,750	5,400	14,300
Alum Feed	17,200	1,000	100	650	18,950
Sodium Hydroxide Feed	10,000	800	200	1,200	12,200
Filter Aid Feed	2,300	1,750	300	2,000	6,350
Sodium Silicate Feed	14,500	1,260	100	650	16,510
Admin., Maint., and Lab Bldg.	-	10,500	4,200	40,000	54,700
Total	48,000	51,210	18,990	95,100	213,300

* $0.07 per kw-hr

+ $10 per man-hr

TABLE C-7. CAPITAL COST ESTIMATE FOR A 5 MGD (18.9 ML/d) DIRECT FILTRATION PLANT AT ONEIDA, N.Y. (JAN. 1982 DOLLARS)

Item	Construction Cost $
In-Line Mixer	10,000
Flocculation	118,000
Filtration	582,000
Backwash Pumping	85,000
Clearwell	145,000
Sludge Lagoons	27,500
Chlorine Feed	40,000
Cationic Polymer Feed	10,000
Filter Aid Feed	27,000
Sodium Hydroxide Feed	20,000
Sodium Silicate Feed	34,000
Admin., Maint., and Lab Bldg.	80,000
Subtotal	1,178,500
Sitework @ 5%	59,000
Total Construction Cost	1,237,500
General Contractor's OH and Profit @ 12%	148,500
Subtotal	1,386,000
Engineering @ 10%	138,600
Subtotal	1,524,600
Land (owned by city)	0
Subtotal	1,524,600
Legal, Fiscal, Admin.	21,400
Subtotal	1,546,000
Interest during Construction @ 10% rate	124,000
Total Capital Cost	1,670,000

TABLE C-8. O&M COST ESTIMATE FOR A 5 MGD (18.9 ML/d) DIRECT FILTRATION PLANT AT ONEIDA, N.Y. (60% CAPACITY, JAN. 1982 DOLLARS)

Item	Chemical ($/yr)	Energy* ($/yr)	Maint. Matl. ($/yr)	Labor+ ($/yr)	Total ($/yr)
In-Line Mixer	-	-	-	-	0
Flocculation	-	120	870	1,500	2,490
Filtration	-	12,350	5,500	22,000	39,850
Backwash Pumping	-	1,200	1,450	2,200	4,850
Clearwell	-	-	-	-	0
Sludge Lagoons	-	200	100	1,000	1,300
Chlorine Feed	4,000	2,150	2,750	5,400	14,300
Cationic Polymer Feed	28,000	1,000	100	1,000	30,100
Sodium Hydroxide Feed	5,000	650	200	1,200	7,050
Filter Aid Feed	2,300	1,750	300	2,000	6,350
Sodium Silicate Feed	14,500	1,260	100	650	16,510
Admin., Maint., and Lab Bldg.	-	10,500	4,200	40,000	54,700
Total	53,800	31,180	15,570	76,950	177,500

* $0.07 per kw-hr

+ $10 per man-hr

TABLE C-9. CHEMICAL COSTS* (JAN. 1982 DOLLARS)

Chemical	Unit	Unit Price
Chlorine	lb	$0.11
Liquid Alum (~48.6% $Al_2(SO_4)_3 \cdot 14H_2O$)	lb	0.036
Cationic Polymer	lb	0.76
Polymer Filter Aid	lb	2.60
Liquid NaOH (~50% NaOH)	lb	0.148
Sodium Silicate	lb	0.053
Soda Ash	lb	0.073
Zinc Polyphosphate	lb	1.81

*Cost information supplied by the Canton and Oneida, New York water treatment plants; except the cationic polymer which is based on manufacturer's quotation.